

Future Needs for Medical Imaging in Health Care

**Report of Working Group 1
Medical Imaging Technology Roadmap**

May 1, 2000

This publication is also offered electronically in HTML and PDF formats on the Internet at <http://strategis.ic.gc.ca/medimage>.

For further information about the Medical Imaging Technology Roadmap, please contact:

Diane Law
Project Facilitator
Life Sciences Branch
Industry Canada
235 Queen Street
Ottawa, Ontario, K1A 0H5

Phone: (613) 954-2779
Fax: (613) 952-5822
E-mail : law.diane@ic.gc.ca

© Medical Imaging Technology Roadmap Steering Committee, 2000

Published and distributed by Industry Canada on behalf of the Medical Imaging Technology Roadmap Steering Committee. The views expressed are those of the authors and not necessarily those of the Government of Canada.

Aussi disponible en français sous le titre *Besoins futurs en imagerie médicale dans les soins de santé*. Une version électronique du document français est disponible à l'adresse suivante : <http://strategis.ic.gc.ca/imagemed>.

Catalogue No.: C21-30/1-2000E
ISBN: 0-662-29040-2

PREFACE

This report of the “Future Needs for Medical Imaging in Health Care” Working Group is the first of five that, once completed, will comprise the Medical Imaging Technology Roadmap. This Roadmap is intended to provide a market-driven forecast of technologies needed to improve patient care and enhance the global competitiveness of the Canadian medical imaging sector. The Roadmap should strengthen technology development, diffusion and adaptation and help to guide public and private sector decision making with respect to product development, investment, human resources and other policy areas.

Overall direction and guidance for this project is provided by the 14-person Medical Imaging Technology Roadmap Steering Committee (see Appendix A for the membership list). Steering Committee members represent companies, researchers, clinicians and government organizations involved with the Canadian medical imaging sector. Industry Canada serves as a catalyst and facilitator of the roadmapping process. A total of 75 people representing more than 50 organizations are participating in the project, creating opportunities for potential alliances and information sharing.

The major accomplishments to date, in addition to this report, are as follows:

- Publication of “Medical Imaging: Discussion Paper”;
- Articulation of the vision, purpose and goal of the project;
- Development of a “members only” web site to facilitate communications;
- Establishment and tasking of five working groups:
 - WG1 - Future Needs for Imaging in Health Care
 - WG2 - Image Generation and Capture
 - WG3 - Transmission and Connectivity
 - WG4 - Image Analysis and Visualization and
 - WG5 - Emerging Technologies; and
- Identification by the Working Groups of issues to be addressed and critical technologies to be examined in the Roadmap.

The projected date for completion of the Medical Imaging Technology Roadmap is Fall 2000. For up-to-date information, visit the public web site at <http://strategis.ic.gc.ca/medimage>.

EXECUTIVE SUMMARY

Introduction

This report of the "Future Needs for Medical Imaging in Health Care" Working Group focusses on the overarching factors that will impact on imaging practice and research in the next five to ten years. Implicit in this examination is an analysis of the present constraints on diagnostic imaging as well as a description of the opportunities presented from an industrial perspective. While this analysis has a Canadian orientation, it equally recognizes that radiology and related sciences (imaging) have become global in both their clinical and industrial contexts

Background: The Radiological Sciences. Röntgen discovered x-rays a little over 100 years ago. In the ensuing time, radiology has grown to encompass the use of many types of electromagnetic radiation (ultrasound, gamma radiation, magnetic fields and radiofrequency radiation, etc.) in making increasingly powerful diagnostic images of the body and its diseases in life. The diversity of energies and specialties (radiology, nuclear medicine, medical physics, nuclear pharmacy, information science, etc.) has led to hospital and university departments being variously called "diagnostic imaging" or "radiology" or "radiological science."

The Impact of Demographic Changes on Medical Imaging

The elderly are major consumers of health care and imaging services. Since 80% of illness occurs in the last 20% of life, the impact of projected demographic changes will create huge demands on care and resources, including imaging services. The 9.8 million Canadian "baby-boomers" who began to reach their fifties in 1997 will exacerbate this situation.

The Impact of Changes in Medicine on Medical Imaging

Health care reform had been overdue but too often its unfolding in the last decade has been at the expense of investment in infrastructure and has failed to achieve real reform of obsolescent methods of accounting and analysis. Less than 3% of health care costs in the U.S. are due to radiology. However, faced with fiscal exigency, governments at all levels have looked to achieve savings by reducing capital spending on plant, information systems and technology. This has been short-sighted. Industry in general had long ago come to understand that these were key strategic investments if a business was to maintain competitiveness. Unfortunately, that lesson has often not been incorporated into health care policy development.

Cutbacks in training positions of five years ago are now coming to be seen as shortsighted as **human resource shortages** are compounded by the decaying technological infrastructure that makes recruitment and retention difficult.

Medicine itself is evolving rapidly into an era of **molecular medicine** and genomics, as disease mechanisms come to be understood in terms of fundamental molecular and genetic disorders, rather than those dealing with cells or organs and end results. In the next decades, the application of these technologies to medical practice will make great demands on functional imaging techniques in particular.

The **evidence-based medicine movement** promises to bring some rationality to the use of imaging in medical practice, but, unless used wisely, it could threaten the development and spread of new technologies.

The Impact of Changes in Technology on Medical Imaging

Imaging, or radiological science, has come to include not only diagnostic methods but treatments using image-guided methods. Increasingly, it depends not only upon the primary diagnostic technologies, but also on information science, networking, image-archiving and image-distribution, contrast agent development, instrumentation, and treatment using physical energies as diverse as high-frequency ultrasound, radiofrequency radiation, etc. Not only are these diverse technologies an opportunity for Canadian industry but their application represents a strategic direction by which, in part, superb health care can continue to be delivered to Canadians using the greatly diminished resources likely to be available in the foreseeable future.

Meanwhile new and more interventionalist approaches to diseases such as stroke will themselves further increase that demand. In parallel, technological innovation creates its own imperative allowing for the use of diagnostic and interventional techniques (not hitherto available) to screen for and treat disease.

Conclusions and Recommendations

Medical imaging technology has enormous potential to contribute to the improvement of health care in this new century and will, no doubt, have the power to contribute to solving some of the financial pressures which also beset health care. And yet, there are serious deficiencies in imaging and other technology penetration into the health care system which must be addressed.

To address these deficiencies, the Working Group on “Future Needs for Medical Imaging in Health Care” makes the following recommendations:

- 1. Canadian industry must become aware of the opportunities in the analysis, transmission and storage of medical images. These opportunities increasingly depend upon technologies (e.g., image compression, broadband communications technology, etc.) other than those primarily involved with image generation.**

- 2. Society and health-care policy makers must recognize the need to plan for an increased capacity for imaging in the future. There is an urgent need to repair the results of years of under funding of capital investment and infrastructures in Canadian hospitals and clinics. To address the human resource shortage, strategies to retain and repatriate Canadian radiologists need to be developed.**

- 3. The health-care system needs to develop budgetary tools and financial systems which permit and facilitate cost-effective technological innovation. Health-care funding, including capital cost amortization, needs to be stable and predictable, and independent of political uncertainties.**

TABLE OF CONTENTS

PREFACE	i
EXECUTIVE SUMMARY	ii
Introduction	ii
The Impact of Demographic Changes on Medical Imaging	ii
The Impact of Changes in Medicine on Medical Imaging	ii
The Impact of Changes in Technology on Medical Imaging	iii
Conclusions and Recommendations	iii
Part 1: INTRODUCTION	1
Scope	1
Membership	1
Background: The Radiological Sciences (Diagnostic Imaging)	1
Outline	2
Part 2: THE IMPACT OF DEMOGRAPHIC CHANGES ON MEDICAL IMAGING	3
World Population Demographics	3
Trends in World Population Demographics	3
Leading Causes of Death	3
The Impact on Procedures Used in Screening For, or Treating, Common Causes of Death and Disease	4
Cardiovascular diseases	4
Cerebrovascular diseases	4
Neoplasms	5
Technological and Medical Changes as They Impact Screening For, or Treating, the Leading Causes of Death and Disease	5
Cardiovascular diseases	6
Cerebrovascular diseases	6
Neoplasms	6
Part 3: THE IMPACT OF CHANGES IN MEDICINE ON MEDICAL IMAGING	7
Health Care Reform	7
Improving Care - Rising Costs	7
Reduced Capital Reinvestment	7
Evolving Technology	7
Silo-Funding in a System with Archaic Accounting	8
Human Resources	8
Medicine and Molecular Biology	9
Functional Imaging	9
Image-Guided Minimally Invasive Procedures	9
<i>Future Needs for Medical Imaging in Health Care</i>	

Pharmacotherapeutic Imaging	9
The Evidence-Based Medicine Movement	10
Part 4: THE IMPACT OF CHANGES IN TECHNOLOGY ON MEDICAL IMAGING ..	11
The <i>Status Quo</i>	11
Changes in Technology	12
Magnetic Resonance Imaging and Spectroscopy	12
Ultrasound	12
CT	13
Radiography: Plain X-Ray Imaging	13
Computed Radiography/Digital Radiography	13
Information Display, Analysis, Transmission and Storage	13
Computer-Aided Diagnosis	13
Nuclear Medicine	13
Optical Methods and Photonics	13
Image-Guided Minimally Invasive Diagnosis, Intervention, and Therapy ...	14
New Signals	14
Multi-Modality Systems	14
Part 5: CONCLUSIONS AND RECOMMENDATIONS	15
APPENDIX A: Medical Imaging Technology Roadmap Steering Committee	1
APPENDIX B: Working Group 1 - Membership List	3
APPENDIX C: Leading Causes of Death in the U.S. (1997)	4
APPENDIX D: Leading Causes of Death in the U.S., by Age Group	5
APPENDIX E: Calculation of Investment Required by Canada in High-Tech Diagnostic Equipment	7
APPENDIX F: Capital Equipment at Eight Canadian Institutions, Fiscal 1997 - 98	8
REFERENCES	9

Part 1: INTRODUCTION

Scope

The scope of the “Future Needs for Medical Imaging in Health Care” Working Group was to focus, within a global context, on future directions in health care and its delivery, as well as on clinical demands, market needs and trends, changes in disease prevalence and demographics. The purpose was to:

- examine the *status quo*;
- identify any deficit in enabling technologies;
- provide a context for industrial developments;
- show how technology could enhance the quality and timeliness of patient care; and
- facilitate planning by public and private policy makers.

A five-year time horizon, with a longer perspective up to ten years, was used although it was recognized that any view of the future beyond a five year horizon, in a dynamic field, must be very speculative. Current technology and its dissemination and penetration was reviewed as a springboard for examining future needs and the impact of technology on quality of care. Finally, the Working Group addressed system needs in information and communications technology as they relate to clinical needs.

Membership

The “Future Needs for Medical Imaging in Health Care” Working Group included representatives of the corporate sector, medical physics, technologists and clinicians. A complete membership list is found in Appendix B.

Background: The Radiological Sciences (Diagnostic Imaging)

An ability to image the human body, both to diagnose disease and guide biopsy and surgery, has become central to the practice of medicine during the 105 years since Röntgen’s discovery of x-rays^{1,2}. In the ensuing time, radiology has grown to encompass the use of many forms of electromagnetic radiation (ultrasound, gamma radiation, magnetic fields and radiofrequency radiation, etc.) in making increasingly powerful diagnostic images of the body and its diseases in life¹. The diversity of energies and specialties (radiology, nuclear medicine, medical physics, nuclear pharmacy, information science, etc.) has led to hospital and university departments being variously called “diagnostic imaging” or “radiology” or “radiological science.” No name yet devised is entirely satisfactory in the face of the dramatic changes which have occurred, particularly in the most recent three or four decades.

The power of modern computers to allow the rapid display of sectional images of the body using technologies such as ultrasonography (US), computed tomography (CT), single-photon emission tomography (SPECT), positron emission tomography (PET) or magnetic resonance imaging (MRI) has been central to the growth of the new technologies. However, an equally great change has been that involving the move of “imaging” from the laboratory to the bedside. Forty years or so ago what was then “radiology” provided a limited range of diagnostic information to a referring physician anxious to resolve diagnostic uncertainty between the diseases potentially able to account for a patient’s symptoms. At the beginning of the twenty-first century, “imaging” is used not only to identify the lesion, and to do so more powerfully, but to guide the needle used in its biopsy; not only to locate an abscess but to guide its drainage; not only to identify a blocked blood vessel but to guide its dilatation, etc.

It is evident that imaging services can replace some expensive surgical procedures (biopsies, drainages, exploratory operations) and have done much to facilitate the dramatic falls in patient lengths-of-hospital-stay. The latter trend will continue as hospital care adjusts to the financial realities of this new century. In that sense, diagnostic imaging is a strategic tool vital to the health and sickness care of the future. The newer technologies (CT, MRI, PET, etc.) produce images that are intrinsically digital and radiology as a whole is moving away from film-based image storage. The result will be a specialty linked to the information age for image storage and transfer³. The opportunities this fact creates are boundless.

Outline

This report is divided into five parts:

1. Introduction
2. The impact of demographic changes
3. The impact of changes in medicine
4. The impact of changes in technology
5. Conclusions and recommendations

The chapter also contains a number of appendices and a list of references.

Part 2: THE IMPACT OF DEMOGRAPHIC CHANGES ON MEDICAL IMAGING

World Population Demographics

A characteristic of populations in developed societies in 2000 is the relatively high proportion of elderly people. This proportion is also enlarging due to increases in life expectancy. In considering the role that medical imaging will play in the future of health care, it is useful to reflect on current demands for service in relation to population demographics, and then to project these into the future based on forecasted global and national population trends. According to United Nations' data concerning the 1999 global population, Japan, Western Europe and the United Kingdom presently have 20-24% of their populations over the age of 60. In North America, China, Russia, and Australia, the percentage of people over age 60 ranges from 10-19%, while in the under-developed countries, it is estimated to be from 0-9%⁴. Many diseases are more prevalent in the elderly⁵. Thus more medical imaging procedures per capita are performed on adults than on children; and on older than on younger adults. It follows that as the proportion of elderly people increases, the demand for imaging procedures will also increase.

Trends in World Population Demographics

United Nations' data indicate that by the year 2050 Canada, Eastern and Western Europe, Russia, and China will have greater than 30% of their population over 60 years of age. The U.S. and Australia will have 25-29% of their population in this category, while South America, India, and the Middle East will have 20-24%. Most of Africa will have between 0-19% of their population over 60 years of age⁴.

It appears that, by and large, people in the Northern Hemisphere will have longer life spans as a result of advances in medical technology and disease control. The under-developed nations will continue to have historical patterns of disease prevalence, exhibiting the classic "pyramid-shaped" population profile, while the developed nations will exhibit "columnar" or "light-bulb" shaped age profiles as "baby boomers" grow older. Canada has 9.8 million "baby boomers", the first of whom began turning 50 years of age in 1997. This, added to the major trend towards an aging population, will place seriously increasing demands on Canada's health care system⁶, not the least of which will be in diagnostic imaging.

Leading Causes of Death

Data are available on the leading causes of death by age group. Space does not permit an exhaustive review of such data here but some trends can be highlighted (see Appendices C and D for additional information). In 1997, accidents were the leading cause of death in the United States in the 1-4, 5-14, 15-24, and 25-44 year-old categories. Cancer was the leading

cause of death in the 45-64 year-old group, a position held by heart disease in the 65+ age group. Diseases of the heart and certain malignant neoplasms constituted the five leading causes of death in the population as a whole after one year of age. The 15 leading causes of death in 1997 accounted for 84.6% of all deaths in the U.S.⁷.

Information on the leading causes of death can assist practitioners and manufacturers in making strategic decisions about directions in which to concentrate their efforts. Manufacturers will likely concentrate on designing equipment and accessories to enable practitioners to diagnose disease and evaluate its progress. Practitioners will selectively choose equipment and accessories that will best suit the demographics of their local practice as well as their specialty.

The Impact on Procedures Used in Screening For, or Treating, Common Causes of Death and Disease

Due to population aging, over the next 4 to 10 years there will be a marked increase in the number of individuals over 65 years of age, as described above. Accordingly, there will be an increase in the number of patients presenting with the three leading causes of death: cardiovascular disease, cerebrovascular diseases and malignant neoplasms. These patients will require imaging for screening, diagnosis, staging and treatment. What follows is a more detailed description of the imaging procedures often used in cardiovascular and cerebrovascular diseases, and the most common cancers.

Cardiovascular diseases: The most important need is the detection of coronary artery atherosclerotic disease revealed as coronary calcifications and coronary artery stenosis, with emphasis on non-invasive procedures such as CT and MRI. Equally important is the study of the impact of coronary occlusive disease on heart perfusion and function as measured by heart contractility and output of blood. Again, the emphasis will be on the use of non-invasive procedures such as ultrasound, MRI and radionuclide imaging (nuclear medicine)^{8,9}.

Cerebrovascular diseases: Disease of the blood vessels supplying the brain is associated with high morbidity and large costs to the health care system. Efforts will be directed not only to accurate, non-invasive detection of cerebral occlusive disease but also to early, efficient and safe treatment of this disease. Detection of carotid and vertebral artery occlusive disease will be performed with non-invasive procedures such as doppler ultrasound and MR angiography. In addition, imaging procedures will be required to assess the effects of chronic cerebrovascular occlusive disease on brain parenchyma with functional MRI procedures such as brain perfusion studies. Results of these studies will be useful for choosing the appropriate revascularization procedure to treat the disease.

Diagnosis and management of stroke is another important and increasing need. Emphasis will be on early detection, speedy diagnosis and triage, followed by treatment with neuroprotective or thrombolytic agents. CT and MRI will be the main imaging procedures in acute stroke and will include both morphological and functional assessment of the brain. Quantification of the amount of reversible and irreversible parenchymal brain damage will be required together with morphological studies of the blood vessels involved. In addition, biochemical analysis of ischemic tissue may be obtained by MR spectroscopy. Once a diagnosis is made, treatment will be performed by image-guided interventional procedures, combining digital angiography with CT and/or MRI¹⁰.

Neoplasms: The most common malignant neoplasms causing death are those of lung, colorectum, prostate and breast. Efforts will be directed towards screening of individuals at risk, early detection and staging, as well as monitoring treatment response. Demographic changes will increase the number of individuals at risk for some malignant neoplasms, particularly colorectal cancer. Imaging already has an important role in screening for breast cancer. It will also have a central role in screening for colorectal cancer. Once cancers are detected, imaging will be used for follow-up and to monitor treatment effectiveness. In addition, new treatments, such as cryotherapy and various forms of thermal tissue ablation (laser, radiofrequency, focussed ultrasound) are being developed and will use imaging techniques for accurate guidance of the delivery of these tools to destroy cancers¹¹.

Staging of cancers will rely on CT, MRI and, increasingly, positron emission tomography (PET). Examinations of tumour biology and tumour response will depend upon innovations in radiopharmacy¹² and/or functional MRI¹³.

Technological and Medical Changes as They Impact Screening For, or Treating, the Leading Causes of Death and Disease

The impact of medical and technological changes on imaging procedures used in screening and treating cardiovascular and cerebrovascular diseases and common malignant neoplasms is substantial. Advances in medicine now require the availability of highly accurate yet non-invasive imaging procedures that will give qualitative and quantitative information on morphology and function. Indeed, as in heart disease, it is often technological change that drives changes in practice.

A long-standing goal of health care is the early detection of disease, when it is more readily treated. But screening tests have to be very sensitive, be performed at low cost and be readily acceptable to patients¹⁴. Mammography is the only imaging procedure used extensively in this context at present. Image reconstruction methods have been developed to permit virtual bronchoscopy and virtual colonoscopy and similar methods might be applicable elsewhere in the body. Such methods, by replacing physician intensive contrast studies or endoscopy,

might be applicable to new screening initiatives. Equally, technical change such as the replacement of chest radiography with spiral CT, subject to cost effectiveness studies, might favourably change the early diagnosis of lung cancer¹⁵.

Cardiovascular diseases: Multi-detector CT now offers high resolution imaging and rapid studies of coronary artery calcifications. Cardiac MR has also progressed significantly over the last few years. Research continues on coronary angiography using contrast administration. At the same time, morphologic and functional evaluation of the myocardium is now possible using MRI, and includes perfusion studies with new contrast agents and the determination of regional and global contractility as well as cardiac output, particularly using machines designed for cardiac applications^{8,9}.

Cerebrovascular diseases: Cranial MRI is an example of an imaging method now providing a comprehensive evaluation of the brain. Stroke imaging protocols have been developed, including standard pulse sequences, for the evaluation of morphology; diffusion and perfusion pulse sequences to evaluate ischemic penumbra; and MRI angiography to evaluate blood vessel patency. The addition of magnetic resonance spectroscopy (MRS) allows study of brain metabolites in life. Stroke imaging with MRI is an example of a new imaging method that provides added value and with qualitative and quantitative data on morphology and function. It is a consequence of technological innovation and results in improvements in medical treatment and outcomes. Accurate detection of carotid artery stenosis is now possible with MRI following development of new and faster pulse sequences used with contrast injection. Both morphological and functional evaluation of the brain are possible during the same examination with standard diffusion and perfusion pulse sequences¹⁰.

Neoplasms: Screening for lung and colorectal cancer provides another example of the potential impact of technological and medical changes on the techniques used. As noted, screening for pulmonary cancer, as for any other neoplasm, requires a test with high sensitivity. Such an evaluation will be provided by multi-detector CT which will provide a more sensitive method than conventional chest radiographs for detecting pulmonary nodules. Advances in CT technology will also permit virtual colonoscopy, which could become another non-invasive method of screening for colorectal cancer. Subject to demonstrations of their cost-effectiveness, these methods may become widely used in future¹⁶. The wider use of PET in Canada for cancer staging will await the development of a national network to supply 18-fluorine fluorodeoxyglucose such as the one being developed in the U.S.

Part 3: THE IMPACT OF CHANGES IN MEDICINE ON MEDICAL IMAGING

Medicine at the beginning of the 21st century is in transition. One commentator has observed that the care of the sick will change more in the next 20 years than in the preceding 2,000¹⁷. This perception relates both to changes intrinsic to medicine and biology, but also as much to the societal context in which medicine is practised, and health care delivered to the population.

Health Care Reform

Improving Care - Rising Costs: In the recent past, medical developments have come to influence significantly the course of many diseases and modify their outcomes. Costs of care have risen in proportion. This is so despite gains from preventive strategies such as the replacement of “iron lungs” to care for poliomyelitis victims by a vaccine for prevention. Aging populations have served to increase demands upon a system stretched to meet its goals. At the same time, many countries including Canada, having been in deficit spending, are now being forced to re-examine their social and fiscal priorities. In particular, the need for deficit reduction and enhanced spending on education, for example, by countries concerned with global competitiveness has necessarily impacted on the amounts of money available for health care.

For most political jurisdictions in Western society, resources in health care are at a premium. In Canada, long waiting lists, crowded emergency rooms, aging physical plant, limited capital renewal and referrals of patients to the U.S. for care have become the daily substance of news reports¹⁸.

Reduced Capital Reinvestment: In Canada, these fiscal pressures have resulted in very low levels of capital reinvestment in the health care system. Hospitals in particular have suffered since, in many, the capital inventory was already aging and inadequate. Compounding this situation, hospitals had been slow to invest in modern information technology, the acquisition of which has become increasingly important as health care reform unfolds. Canada remains among the top half-dozen countries in terms of spending on health as a fraction of gross domestic product. And yet, by all existing measures the nation has the poorest record of investment in technology, certainly among the developed nations and even in a wider sense^{19, 20}. It is tempting to conclude that this paradox is due, at least in some measure, to a failure to realize the efficiencies that might result from the judicious use of technology.

Evolving Technology: In parallel with those changes intrinsic to the “health care system”, the emergence of powerful diagnostic tools (CT, MRI, PET to name only a few) and therapeutic agents and techniques (antibiotics, antiviral agents, psychotropic drugs, minimally

invasive surgery, again to name only a few) has been matched by a change in the relationship between doctors and individuals. While medicine remains, according to numerous polls, a well-respected profession, patients (often called clients in this new context) now expect to have much more say in their care²¹. The public use of the Internet, with all its limitations as a source of health information, is also empowering patients as never before.

In the face of these massive social forces it has become almost a ritual to blame the escalating costs of health care on technology – expensive machines and their use are an obvious potential scapegoat for such escalation. Imaging devices, such as CT and MRI machines each costing several million dollars are, perhaps, the most visible sources of expense. And yet radiology accounts for less than 3% of health care costs in the U.S. It may be difficult to sustain the argument attributing increasing costs to technology, while the concept that technology may be a source of cost efficiencies, already advanced above, deserves more study^{22,23}.

Silo-Funding in a System with Archaic Accounting: The fiscal climate in which medicine is practised in Canada in 2000 inhibits change, innovation, and the application of cost-effective technology. The imposition of rigid income caps within a fixed specialty structure makes it difficult to innovate in one specialty, even if the results were to realize a net savings, since that service might have to be funded from an inflexible global budget at cost to another specialty. The result is that physicians have been forced, in a protectionist sense, to resist technological innovation since they will end up paying for its introduction out of their own pockets. If this situation and the rigid perpetuation of specialty boundaries persists, medicine, and the public, will suffer as innovation is stifled and cost-effective change is inhibited.

In precisely the era in which radiological methods are evolving to help solve the new fiscal environment of health care reform, global budgeting and “silo” financing have undermined progress. Interventional radiology, for example, has resulted in procedures, hitherto requiring admissions and operating-room time, potentially being done in the radiology department on out-patients. The savings, despite high capital costs, are real but difficult to realize without a “system perspective”. Any view of the future of imaging technology must consider this trend likely to continue. However, innovation is difficult. For example, vast sums are now spent on the treatment of the neuroses and psychoses. Such treatment is almost always on a trial and error basis. If functional imaging methods can fulfill their potential to create a classification of psychiatric disease such that specific remedies might be matched to specific disorders, the savings in medical and social costs would be prodigious. But how will the capacity for such powerful methods be developed, still less delivered? The archaic funding of health care and medical technology thus needs to be revisited to ensure a flexible future different from that of the immediate past.

Human Resources

The uncertainties of the last decade led to a reduction in the numbers of radiologists educated (as of all physicians). In retrospect, the cuts in the number of training positions were misguided. A recent study by the Canadian Association of Radiologists reveals a severe and escalating national shortage of radiologists. Depending upon the variables used in a sensitivity analysis, this shortage amounts to some 100 radiologists nationwide²⁴. It is worthwhile reflecting that this number is not based on any ideological view of ratios of radiologists to population, etc., but on the reality of demand by hospitals and communities seeking to recruit radiologists. The situation is, moreover, compounded by a small but consistent level of emigration by physicians and radiologists. In this context, the depleted and decaying technology inventory in Canada does not help. Canadian graduates trained to work with sophisticated machines often fail to find suitable employment opportunities in their own country.

Medicine and Molecular Biology

Functional Imaging: Röntgen's first images (of his wife's hand) were concerned with the anatomy of the human skeleton. In their time, these images were remarkable enough, revealing structures not hitherto accessible in life. In the 100 years since, imaging technologies have greatly refined the study of structure. Imaging methods have also been directed to studies of tissue and organ function beginning with nuclear medicine methods including single photon emission computed tomography (SPECT) and positron emission tomography (PET), but expanding into functional magnetic resonance imaging (fMRI) and magnetic resonance spectroscopy (MRS). The *in vivo* monitoring of gene therapy, anti-sense imaging and other initiatives will constitute a further imperative to the greater development of functional imaging, while it is now apparent that PET cost-effectively out-performs other imaging methods in, for example, staging many cancers²⁵.

Image-Guided Minimally Invasive Procedures: The development of imaging methods has resonated with another trend impelled by health care reform. With increasing pressures on hospital length-of-stay and the need to reduce the time spent in the operating room on exploratory surgery, there has resulted a burgeoning of minimally-invasive surgery (e.g., laparoscopic cholecystectomy) and minimally-invasive image-guided procedures such as percutaneous biopsies, drainages and angioplasty. These procedures are very cost effective^{26,27,28} apart from being of obvious benefit to the patient. There are yet other examples of strategic imaging techniques that in fact reduce system costs due to reducing the length of admissions and use of conventional operating rooms.

Pharmacotherapeutic Imaging: Traditionally, new drugs have been tested in large and expensive studies of outcome measure. Radiological methods are now being examined

for their potential to study new drugs *in vivo*. More importantly, as medications become more expensive, there will be increasing pressure to determine their efficacy early in the natural history of disease. Cancer chemotherapy, for example, is extremely expensive. At present, techniques to measure individual tumour responsiveness are cheap but insensitive; for example, measuring the potential shrinkage of a tumour from a chest radiograph eight or twelve weeks into therapy. In terms of global savings, it might be better to use more sensitive functional tests of tumour response earlier in the natural history of the disease^{12,29}.

The Evidence-Based Medicine Movement

Historically, medicine has been mostly learned by an apprenticeship. The recent rise of a movement to critically appraise both diagnostic procedures and therapies has gone some way to remedy the use of redundant or irrelevant parts of medicine. Indeed, the need for critical thought has only emerged in the recent past because, until less than a century ago, there were no more than a handful of effective tools available to a physician. While the evidence-based medicine movement has led to reductions in the use of some procedures and elimination of unnecessary duplication, its impact on radiological innovation will not be entirely negative³⁰. Use of computer-based guidelines and decision support will be technology-intensive but will further rationalize practice. Indeed, in the longer view, computer-based records with on-line data about the impacts of interventions on treatment and outcomes will result in on-line real-time interactive applications of evidence to the way medical care is delivered and medicine practised³¹.

Part 4: THE IMPACT OF CHANGES IN TECHNOLOGY ON MEDICAL IMAGING

The Status Quo

The *status quo* is not reassuring^{19, 20, 32}. Canada has 8.1 CT machines per million population while the Organization for Economic Cooperation and Development (OECD) average is 12.9. To reach the OECD level, Canada would need to install 144 CT machines. Additionally, Canada has 1.7 MRI machines per million population. To reach the OECD average of 4.3 per million population, 75 MRI machines would need to be installed nationwide. Canada has fewer than 3% of all PET detectors in the world, with 40% being found in the U.S., 40% in Europe and 11% in Pacific-rim nations. Taking this into account, one could suggest that Canada needs to install 6 PET machines. However, since most of the existing machines in Canada are “small aperture” (i.e. only able to image the head) and are only used for research, the correct number for clinical use is probably nearer 12. A recent Ontario analysis, admittedly by PET advocates, identifies a need for 9 to 12 units in that province alone (see Appendix E for further information).

The Fraser Institute has analyzed technology penetration in Canada, as has Rankin with respect to MRI^{19, 20}. Both analysts find that Canada ranks lowest of the developed nations in imaging technology adoption. Indeed the deficit in technology is so great that Canada has fewer diagnostic machines than many underdeveloped nations.

It must be said that these analyses can be criticized. Accounts of the number of machines per capita tell nothing of their actual use. However, were this correction applied to Canada, the nation might look even worse because imaging machines, particularly MRI machines, are often funded by provinces for limited periods of operation. Equally, in the absence of a supply-and-demand scenario, it must be realized that no public policy has evolved world-wide to establish what is the optimum supply of high-technology imaging devices per capita of population. Nevertheless, there must be the presumption that because Canada is outstripped by nations that are both similarly developed as well as those that are much less developed, it is unlikely the optimum level has been achieved.

An 1997/98 OECD survey³² of Canadian tertiary and quaternary hospitals showed that, not only does Canada have a deficit in the high-technology aspect of imaging, but that hospital clinical services have somewhat uniformly obsolescent machines. The data may contain a response bias; however, since the major regions (Maritimes, Quebec, Ontario, Prairies and West Coast) were all represented, this is unlikely to be a major factor. Survey results, obtained from eight institutions, reported the mean age of the machines and the number upon which the mean was based as well as the sizes of the capital inventories, the amount of capital reinvested and the reinvestment rate. In this fiscal year, all institutions fell short of, and many well short of, a 10% per annum reinvestment rate, which would be considered prudent in

other industries. In fact, the mean reinvestment rate of the eight institutions was 5%, with two at 0% and the remainder ranging from 5 to 9% (see Appendix F for further information).

Changes in Technology

The following is a list of changes in technology that are likely to occur over the next three to five years. The list is partly segregated by imaging method but some trends encompass more than one modality. Where this sort of overlap occurs, some new technologies are listed more than once.

In addition to the changes in specific instrumentation, some general themes are also apparent. These include:

- integration in the presentation of information and images from multiple modalities;
- a larger role for image-guidance and monitoring of interventional techniques;
- expansion of imaging beyond representations of anatomy to include functional, physiological, quantitative and dynamic information;
- integration with molecular biology technologies, e.g., detection of delivery of genetic probes, targeted delivery of genetic material, etc.;
- a general emphasis on faster, three-dimensional or volumetric imaging;
- faster and more detailed imaging of all types using more powerful computers; and
- the use of computers in image analysis and decision support.

Magnetic Resonance Imaging and Spectroscopy: A greater variety in choices of equipment and a broader range of magnets and systems will be developed, generating opportunities for developing and marketing devices, accessories, and image processing software. New MRI contrast agents for dynamic and functional studies will emerge, increasingly coupled with molecular biologicals. MRI will develop major clinical roles in the guidance and monitoring of minimally-invasive interventional techniques and there will be opportunities for the development and manufacture of MRI-compatible devices and equipment³³.

Ultrasound: Major developments are anticipated in ultrasound imaging based on the development of new contrast agents. Innovative and complicated operating modes will be developed to exploit these new contrast agents. In general, instrumentation is becoming more specialized, utilizing higher frequencies and more complex transducers, with emphasis on miniaturization for intravascular and interstitial imaging. Systems will continue to become more portable³⁴.

CT: Emphasis will be placed on faster imaging methods, creating a need to develop new x-ray tubes, detectors, image reconstruction display methods, etc. Special purpose machines will be developed such as trauma CT, low-cost C-arm and mobile units. There will be opportunities for the development of accessories and devices, particularly for dynamic studies^{35,36}.

Radiography: Plain X-Ray Imaging: There will be major developments in digital technologies for both detectors and display. Image-processing software will find increasing clinical applications. There will be emphasis on smaller, mobile systems and there will continue to be developments in x-ray tubes and other innovative x-ray sources.

Computed Radiography/Digital Radiography: The film-screen combination currently used to capture radiographic images will soon be replaced by digital acquisitions, so that the entire array of imaging modalities can be part of the electronic patient record. The advent of digital detectors will likely play a major role in acquisition of static (digital radiography) as well as dynamic (digital fluoroscopy) images³⁷.

Information Display, Analysis, Transmission and Storage: Once plain x-rays and fluoroscopy have been converted to digital acquisition, all medical imaging modalities will be read off computer monitors, transmitted instantly wherever they are needed, and archived electronically. The continuous progress made in network communication and computer technology will allow development of new organizational models for imaging departments with a trend towards large global networks, decentralization and globalization of the medical imaging business³⁷.

Computer-Aided Diagnosis: Computer-aided diagnosis will be a side benefit of the migration towards a totally electronic format. Specialized software will be developed in order to support radiologists and clinicians in the diagnosis process. The capability for convenient multi-modality image registration and display will accelerate this trend³¹.

Nuclear Medicine: One key technology for nuclear medicine remains the development of radiopharmaceuticals and here molecular imaging techniques are anticipated to have great impact¹². Developments in instrumentation will continue to focus on special purpose systems, e.g., economical PET imaging, as well as high resolution gamma cameras³⁸.

Optical Methods and Photonics: Visible light techniques (including ultraviolet and infrared) will play bigger roles in medical imaging in the future. Molecular biology techniques will develop specific labels (e.g., fluorescent proteins) which will be detectable with interstitial probes for local measurements of tissue function and disease, with the potential for *in vivo* biopsy. Transillumination and optical computed tomography techniques will undergo further development³⁹.

Image-Guided Minimally Invasive Diagnosis, Intervention, and Therapy:

Interventional techniques will increasingly exploit imaging technologies that will enable improved and new interventional technologies to be developed. Minimally invasive, day-surgery techniques to avoid or reduce hospital stays will involve various imaging tools and specialized operating-room equipment. Thermal therapy techniques for tumour ablation will evolve, and robotic technologies will be increasingly used, to bridge imaging and interventional technologies. Interstitial probes will be increasingly applied as sensors for diagnosis and monitoring and for guiding and assessing delivery of agents for diagnosis and therapy⁴⁰.

New Signals: There are still some observational windows into the body which can be developed. Likely candidates are electrical impedance tomography and magnetoencephalography (MEG), as well as high-resolution optical imaging.

Multi-Modality Systems: Exciting combinations of technologies will be developed. For example, the combination of the rotational technologies of CT and SPECT will be more powerful than either alone. X-ray angiography techniques will be combined with ultrasound, CT or MRI to provide better definition of the vascular system for diagnosis, treatment and interventions. Magnetoencephalography (MEG) will gain power when combined with simultaneous PET or fMRI imaging.

Part 5: CONCLUSIONS AND RECOMMENDATIONS

A number of influences have been described which suggest an increasing demand for imaging technology. These include, but are not limited to, demographic factors, technological evolution and, not least, changes in the very nature of medical practice. Canadian hospitals and clinics enter the 21st century with limited inventories of often obsolete equipment. This is a handicap which will, unless corrected, represent a hidden deficit to be passed on to our descendants.

Medical imaging technology has enormous potential to contribute to the improvement of health care in this new century and will, no doubt, have the power to contribute to solving some of the financial pressures which also beset health care. And yet, there are serious deficiencies in imaging and other technology penetration into the health care system which may impact, not only upon care itself, but on our national capacity to benefit from industrial innovation in this context.

To address these deficiencies, the Working Group on “Future Needs for Medical Imaging in Health Care” makes the following recommendations:

- 1. Canadian industry must become aware of the opportunities in the analysis, transmission and storage of medical images. These opportunities increasingly depend upon technologies (e.g. image compression, broadband communications technology, etc.) other than those primarily involved with image generation.**
- 2. Society and health-care policy makers must recognize the need to plan for an increased capacity for imaging in the future. There is an urgent need to repair the results of years of under funding of capital investment and infrastructures in Canadian hospitals and clinics. To address the human resource shortage, strategies to retain and repatriate Canadian radiologists need to be developed.**
- 3. The health-care system needs to develop budgetary tools and financial systems which permit and facilitate cost-effective technological innovation. Health-care funding, including capital cost amortization, needs to be stable and predictable, and independent of political uncertainties.**

Advocacy of technology in health care risks appearing to disregard the caring and compassionate attributes of medicine as an essentially humanitarian enterprise. Technology is a necessary, but not sufficient, part of medical practice and it will depend upon the many people involved to ensure that machines subserve care and do not de-humanize it. To tap the enormous potential of the radiological and related sciences to contribute to health care, in this new century, requires an understanding of both the potential and the limitations of technology. However, excellence in diagnosis and treatment is ultimately a major component of compassionate care.

Medical Imaging Technology Roadmap Steering Committee

Chairperson:

Dr. Aaron Fenster
Director, Imaging Research Laboratories
The John P. Robarts Research Institute
London, Ontario
E-mail: afenster@irus.rrri.on.ca

Members:

Dr. Michael Barry
Department of Diagnostic Imaging
Saint John Regional Hospital Facility
Saint John, New Brunswick
E-mail: drmikeybarry@health.nb.ca

Mr. Fred Doern
nir-vivo inc.
c/o NRC - Institute for Biodiagnostics
Winnipeg, Manitoba
E-mail: doern@nir-vivo.com

Dr. Robert Ferguson
Chief, Radiology Department
Kingston General Hospital
Kingston, Ontario
E-mail: fergusor@kgh.kari.net

Mr. Doug Morrison
Senior Manager
Deloitte & Touche LLP, Management Solutions
Toronto, Ontario
Email: doug.morrison@bmts.com

Dr. Douglas Mowbray
(Canadian Association of Radiologists)
Radiologist, Various Rural Hospitals
Lucknow, Ontario
E-mail: dmowbray@hurontel.on.ca

Mr. Bruce Davey
Director, Engineering
Surgical Products Group
Cedara Software.
Mississauga, Ontario
E-mail: bruce.davey@cedara.com

Mr. Bill Dobson
Industrial Technology Advisor
Industrial Research Assistance Program (IRAP)
Toronto, Ontario
E-mail: bill.dobson@nrc.ca

Dr. Brian C. Lentle
Professor Emeritus and Former Head
Dept. of Radiology
Vancouver General Hospital
Vancouver, B.C.
E-mail: blentle@interchange.ubc.ca

Mr. Len Grenier
V.P. Engineering & Chief Technology Officer
A.L.I. Technologies Inc.
Richmond, British Columbia
E-mail: len@alitech.com

Dr. Louis Renaud
Vice President, Research and Development
Electromed International Ltd.
Saint-Eustache, Quebec
E-mail: louis.renaud@electromed.ca

Mr. Bill Brodie
(Canadian Association of Medical Radiation
Technologists)
Manager, Medical Imaging
Montreal Neurological Institute and Hospital
Montreal, Québec
E-mail: william.brodie@muhc.mcgill.ca

Mr. Jim Herrewynen
General Manager
Mitra Imaging Inc.
Waterloo, Ontario
E-mail: Eric@mitra.com

Dr. John Rowlands
Professor, U. of Toronto
Dept. of Medical Biophysics and Medical Imaging
Sr. Scientist, Sunnybrook & Women's College Health Sciences Centre
Toronto, Ontario
E-mail: rowlands@srcl.sunnybrook.on.ca

Working Group 1 - Membership List

Co-Leaders:

Dr. Brian C. Lentle
Professor Emeritus and Former Head
Dept. of Radiology
Vancouver General Hospital
Vancouver, British Columbia
E-mail: blentle@unixg.ubc.ca

Dr. Walter Kucharczyk
Professor and Chair
Dept. of Medical Imaging
University of Toronto
Toronto, Ontario
E-mail: w.kucharczyk@utoronto.ca

Dr. Michael Bronskill,
Director, Imaging Research
Sunnybrook & Women's College Health Sciences
Centre
Toronto, Ontario
E-mail: michael.bronskill@swchsc.on.ca

Members:

Dr. Patrice Bret
Professor, University of Toronto
Radiologist-in-Chief
Medical Imaging Department
Mount Sinai Hospital & University Health Network
Toronto, Ontario
E-mail: pbret@mtsina.on.ca

Mr. Bill Brodie
(Canadian Association of Medical Radiation
Technologists)
Manager, Medical Imaging
Montreal Neurological Institute and Hospital
Montreal, Quebec
E-mail: william.brodie@muhc.mcgill.ca

Mr. Joe Sardi
General Electric Medical Systems
Mississauga, Ontario
E-mail: joe.sardi@med.ge.com

Dr. Jill M. Sanders
President
Canadian Coordinating Office for Health
Technology Assessment (CCOHTA)
Ottawa, Ontario
E-mail: jills@ccohta.ca

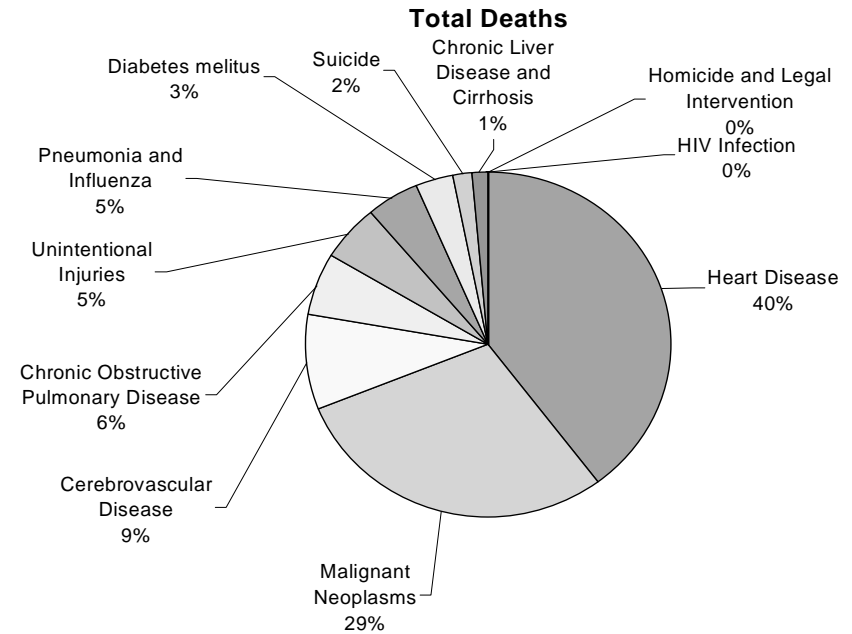
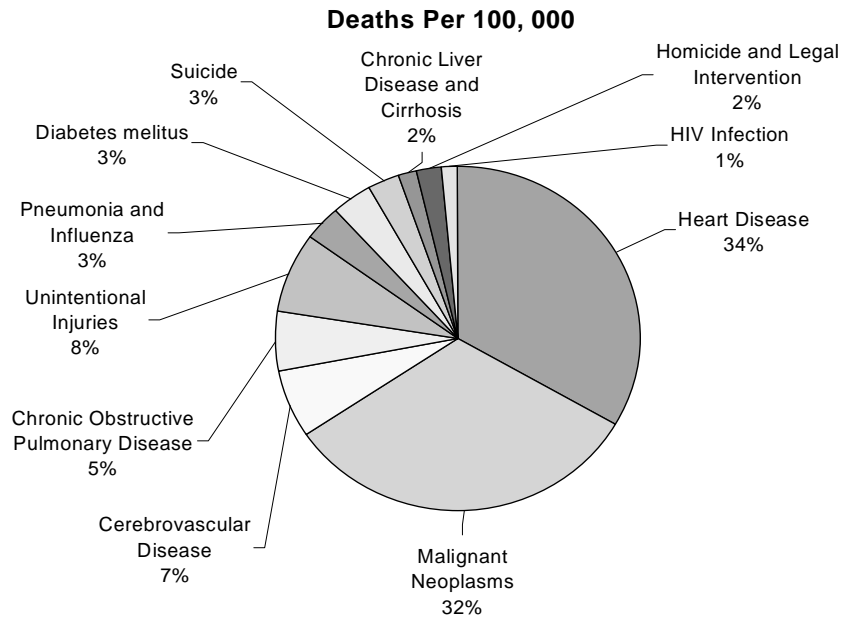
Dr. David Fraser
Past President, RSNA
Former Chief, Diagnostic Imaging Dept.
QEII Health Sciences Centre
Halifax, Nova Scotia
E-mail: fraser@rsna.org

Dr. Pierre Bourgouin
Professor of Radiology,
University of Montréal
Associate Chief, Department of Radiology,
University of Montréal Medical Centre
Montréal, Québec
E-mail: bourgou@attglobal.net

Secretariat:

Diane Law
Life Sciences Branch
Industry Canada
235 Queen Street
Ottawa, Ontario K1A 0H5
E-mail: law.diane@ic.gc.ca

Leading Causes of Death in the U.S. (1997)



Cause of Death	All	Male	Female	Cause of Death	All	Male	Female
Heart Disease	130.5	173.1	95.4	Heart Disease	727 334	356 958	370 376
Malignant Neoplasms	125.6	150.4	107.3	Malignant Neoplasms	539 577	281 110	258 467
Unintentional Injuries	30.1	42.9	17.8	Cerebrovascular Disease	159 791	62 564	97 227
Cerebrovascular Disease	25.9	27.9	24.2	Chronic Obstructive Pulmonary Disease	109 029	55 984	53 045
Chronic Obstructive Pulmonary Disease	21.1	26.1	17.7	Unintentional Injuries	95 644	61 963	33 681
Diabetes melitus	13.5	14.8	12.4	Pneumonia and Influenza	86 449	39 284	47 165
Pneumonia and Influenza	12.9	16.2	10.5	Diabetes melitus	62 636	28 187	34 449
Suicide	10.6	17.4	4.1	Suicide	30 535	24 492	6 043
Homicide and Legal Intervention	8.0	12.5	3.3	Chronic Liver Diseases and Cirrhosis	25 175	16 260	8 915
Chronic Liver Diseases and Cirrhosis	7.4	10.5	4.5	Homicide and Legal Intervention	0	0	0
HIV Infection	5.8	9.1	2.6	HIV Infection	0	0	0

Leading Causes of Death in the U.S., by Age Group

<p>Under one year in age</p> <ol style="list-style-type: none"> 1. Congenital anomalies 2. Disorders relating to short gestation and unspecified low birth weight 3. Sudden infant death syndrome 4. Respiratory distress syndrome 5. Newborn affected by maternal complications of pregnancy 6. Newborn affected by complications of placenta, cord, and membranes 7. Infections specific to the perinatal period 8. Unintentional injuries 9. Intrauterine hypoxia and birth asphyxia 10. Pneumonia and influenza
<p>From 1-4 years of age</p> <ol style="list-style-type: none"> 1. Unintentional injuries 2. Congenital anomalies 3. Malignant neoplasms 4. Homicide and legal intervention 5. Diseases of the heart 6. Pneumonia and influenza 7. Certain conditions originating in the perinatal period 8. Septicemia 9. Benign neoplasms 10. Cerebrovascular diseases
<p>From 5-14 years</p> <ol style="list-style-type: none"> 1. Unintentional injuries 2. Malignant neoplasms 3. Homicide and legal intervention 4. Congenital anomalies 5. Diseases of heart 6. Suicide 7. Pneumonia and influenza 8. Chronic obstructive pulmonary diseases 9. Human immunodeficiency virus infection 10. Benign neoplasms 11. Cerebrovascular diseases

From 15-24 years of age

1. Unintentional injuries
2. Homicide and legal intervention
3. Suicide
4. Malignant neoplasms
5. Diseases of the heart
6. Congenital anomalies
7. Human immunodeficiency virus infection
8. Pneumonia and influenza
9. Chronic obstructive pulmonary diseases
10. Cerebrovascular diseases

From 25-44 years of age

1. Unintentional injuries
2. Malignant neoplasms
3. Diseases of the heart
4. Suicide
5. Human immunodeficiency virus infection
6. Homicide and legal intervention
7. Chronic liver diseases and cirrhosis
8. Cerebrovascular diseases
9. Diabetes mellitus
10. Pneumonia and influenza

From 45-64 years of age

1. Malignant neoplasms
2. Diseases of heart
3. Unintentional injuries
4. Cerebrovascular diseases
5. Chronic obstructive pulmonary diseases
6. Diabetes mellitus
7. Chronic liver disease and cirrhosis
8. Suicide
9. Pneumonia and influenza
10. Human immunodeficiency virus infection

From 65 years and over

1. Diseases of heart
2. Malignant neoplasms
3. Cerebrovascular diseases
4. Chronic obstructive pulmonary diseases
5. Pneumonia and influenza
6. Diabetes mellitus
7. Unintentional injuries
8. Alzheimer's disease
9. Nephritis, nephrotic syndrome, and nephrosis
10. Septicemia

Source: U.S. Center for Disease Control

Calculation of Investment Required by Canada in High-Tech Diagnostic Equipment

	CT	MRI	Lithotripter	Radiation Therapy Equipment	PET	TOTAL
Average number of units per M population for countries with high per capita GDP (Note 1)	15.7	4.7	1.6	7.6		
Additional units per M population required for Canada to achieve the above average (Note 2)	7.6	3	1.1	0.8		
Total additional units required for Canada to achieve the above average	232	91	33	24 (Note 3)	10 (Note 4)	
Average capital cost* per unit of equipment	1	2.5	1.4	1.8	1.9	
Average siting cost per unit of equipment	0.35	2	0.25	0.5	0.5	
Total capital and siting investment required for Canada to achieve the above average	313.2	409.5	54.5	55.2	24	856.4
85% Factor (Note 5)						151.1
Total investment required for Canada to achieve the above average						1007.5
Average yearly operating cost per unit of equipment	0.5	1.2	0.24	0.25	0.5	
Total yearly operating cost required for Canada to achieve the above average	116	109.2	7.9	6	5	244.1

* All costs/investments are in \$ millions

Source: Canadian Association of Radiologists

Note 1: High per capita GDP is defined as = or > US\$20 000 PPP (Purchasing-power-parity)

Note 2: In 1998, the population of Canada was 30.6 million (Statistics Canada).

Note 3: In 1997, Canada had 47 Cobalt-60 units, 112 linear accelerators and 52 brachytherapy units. Cobalt-60 units are being phased out and replaced by low energy linear accelerators. Also, Canada has relatively few high energy linear accelerators so the 24 additional units would be high energy accelerators.

Note 4: Of the 2000 PETs in the world in 1998, Europe has 40%, the USA 40% and Canada 3% (mostly for research). Accounting for the population and growth of PET, Canada would require an additional 10 units to be equivalent to Europe.

Note 5: Radiological technology equipment represents about 85% of radiological technology capital costs. Therefore, this factor (1/.85), or an increase of 17.65%, was applied to the total investment.

Capital Equipment at Eight Canadian Institutions, Fiscal 1997 - 98

	INSTITUTION							
	1	2	3	4	5	6	7	8
MACHINE Mean age (Number)								
CT*	7 (4)	6 (8)	3 (2)	3 (2)	4 (5)	3 (2)	5 (3)	3 (3)
MRI*	3 (2)	6 (4)	1 (2)	6 (1)	6 (2)	5 (1)	5 (1)	3 (3)
Ultrasound	7 (7)	3 (39)	6 (16)	6 (10)	5 (19)	6 (7)	11 (13)	9 (16)
Gamma cameras	9 (9)	7 (18)	7 (5)	7 (6)	5 (4)	8 (3)	10 (9)	3 (14)
Angiographic units	6 (3)	5 (9)	4 (3)	5 (4)	7 (4)	10 (2)	12 (4)	5 (3)
Lithotripters	1 (1)	-	-	-	-	-	4 (1)	10 (1)
RF units	15 (24)	8 (26)	8 (11)	11 (13)	11 (13)	8 (9)	15 (28)	12 (16)
Fluoro-units	6 (11)	5 (10)	10 (4)	9 (5)	9 (7)	9 (2)	14 (18)	11 (8)
CAPITAL C\$ million								
Capital Inventory	28	60	23	22	30	15	30	33
Capital Reinvestment	0	4	1.2	1.2	2.5	0.8	0	3
Reinvestment Rate	0%	7%	5%	6%	8%	5%	0%	9%

* Age since major upgrade

REFERENCES

1. Röntgen WC. 1896. "On a new kind of rays"(English translation), *Nature*, 53: 274-276.
2. Eisenberg RL. 1992. *Radiology: An Illustrated History*. St Louis: Mosby.
3. Hangiandreou NJ, Young JWR, and RL Morin, *editors*, 1999. *Electronic Radiology Practice - Mechanical and Practical*. Chicago: Radiological Society of North America.
4. United Nations, Publication Division, Department of Economic and Social Affairs. *World Population 1998*. United Nations: 1999.
5. Canadian Institute for Health Information. Provincial Government Hospital Expenditure by Age and Gender, by Province/Territory and Canada 1997. *National Health Expenditures Data 1997*.
6. Foot, David K. with Daniel Stoffman. May 1996. *Boom Bust & Echo: How to Profit from the Coming Demographic Shift*. Chapter 9: *The Health Care Crunch*. Macfarlane Walter & Ross.
7. Hoyert DL, Kochanek KD, and SL Murphy. June 30 1999. "Deaths: Final Data for 1997," *National Vital Statistics Reports*, 47(19): 1-105.
8. Rees M. 1997. "Cardiac imaging: present status and future trends," *Journal of Radiology*, 70: 162-167.
9. Wielopolski PA, va Guens RJ, de Feyter PJ, and M Oudkerk. 1998. "Coronary arteries," *European Radiology*, 201: 798-802.
10. Bogousslavsky J. 1997. "On the attack," *Odyssey*, 3: 2-7.
11. Lewin JS, Connell CF, Duerk JL, Chung Y-C, Clampitt ME, Spisak J, Gazelle GS, and JR Haaga. 1998. "Interactive MRI-guided radiofrequency interstitial thermal ablation of abdominal tumors: Clinical trial for evaluation of safety and feasibility," *Journal of Magnetic Resonance Imaging*, 8(1): 40-47.
12. Ranney DF. 2000. "Biomimetic transport and rational drug delivery." *Biochem Pharmacol*, 59(2): 105-114.
13. Maisey MN and M Dakin. 1998. "The first five years of a dedicated clinical PET centre," *Clinical Positron Imaging*, 1: 59-69
14. Sackett DL, Haynes RB, Guyatt GH, and P Tugwell. 1991. *Clinical Epidemiology: A Basic Science for Clinical Medicine*, 2nd ed., p. 168. Boston: Little Brown and Co.
15. Kaneko M, Eguchi K, Ohmatsu H, Kakinuma R, Naruke T, Suemasu K, and N Moriyama. 1996. "Peripheral lung cancer: screening and detection with low-dose spiral CT versus radiography," *Radiology*, 201: 798-802.

16. Johnson CD, Hara AK, and JE Reed. 1997. "Computed tomography colonography: a new method for detecting colorectal neoplasms," *Endoscopy*, 29: 454-461.
17. Turnberg L. quoted by Smith R. 1997. *Odyssey*, 3: 16-18.
18. Decter, Michael. January 17, 2000. "A Plan to End the Hospital Crisis," *Maclean's*, Roger's Media, 113(03): 28-29.
19. Harriman D, McArthur W, and M. Zelder. 1999. *The Availability of Medical Technology in Canada: An International Comparative Study*. Vancouver: A Fraser Institute Occasional Paper.
20. Rankin RN. 1999. "Magnetic resonance imaging in Canada: dissemination and funding," *Canadian Association of Radiology Journal*, 50: 89-92.
21. Muha L. 1997. "Pillars of Strength," *Odyssey*, 3: 2-4.
22. Binkhuysen FHB, and CBAJ Puylaert. 1998. "Influence of CT on radiologic utilization in the Netherlands," *Radiology*, 169: 827-829.
23. Rao PM, Rhea JT, Novelline RA, Mostafavi AA, and CJ McCabe. 1998. "Effect of computed tomography of the appendix on treatment of patients and use of hospital resources," *New England Journal of Medicine*, 338: 141-146.
24. Campbell DR. 1998. "CAR National Survey: Manpower for Radiology," *Unpublished*.
25. Hoh CK, Glaspy J, Rosen P. et al. 1997. "Whole body FDG-PET imaging for staging of Hodgkin's disease and lymphoma," *Journal of Nuclear Medicine*, 38: 343-348.
26. Baccarani U, Terrosu G, Donini A, Risaliti A, and F. Bresadola. August 7 1999. "Future of minimally invasive surgery[letter]," *Lancet*, 354(9177): 513.
27. Rattner DW. 1999. "Future directions in innovative minimally invasive surgery," *Lancet*, 353(Suppl 1): S112-5.
28. Rattner DW. 1999. "Beyond the laparoscope: minimally invasive surgery in the new millennium," *Surgery*, 125(1): 19-22.
29. Dewanjee MK, Ghafouripour AK, Kapadvanjwala M, Dewanjee S, Serafini AN, Lopez DM, and GN Sfakianakis. 1994. "Noninvasive imaging of c-myc oncogene messenger RNA with indium-111-antisense probes in a mammary tumor-bearing mouse model," *Journal of Nuclear Medicine*, 35: 1054-1063.
30. Lentle BC, and JA Aldrich. 1997. "Radiological sciences, past and present," *Lancet*, 350: 280-285.

31. Hunt DL, Haynes RB, Hanna SE, and K. Smith. 1998. "Effects of computer-based clinical decision support systems on physician performance and patient outcomes: A
32. ~~Systematic Review~~ *Systematic Review*" 1998, Paris: ~~the American Medical Association~~ *Organization and Development*, 280-1339-1346.
33. Gould SWT and A. Darzi. 1997. "The interventional magnetic resonance unit - the minimal access operating theatre of the future." *Brit J Radiol*, 70: S89-S97.
34. Rizzatto G. 1998. "Ultrasound transducers," *European Journal of Radiology*, 27(Suppl2): S188-95.
35. Butler WE, Piaggio CM, Constantinou C, Niklason L, Gonzalez RG, Cosgrove GR, and NT Zervas. 1998. "A mobile computed tomographic scanner with intraoperative and intensive care unit applications," *Neurosurgery*, 42: 1304-1310.
36. Fox SH, Tannenbaum LN, Ackelsberg S, He HD, Hsieh J, and H. Hu. 1998. "Future directions in CT technology," *Neuroimaging Clinics of North America*, 8(3): 497-513.
37. Bick U, and H Lenzen. 1999. "PACS: the silent revolution," *European Radiology*, 9(6): 1152-60.
38. Phelps ME, and RE Coleman. 2000. "Nuclear medicine in the new millennium," *Journal of Nuclear Medicine*, 41: 1-4
39. Alfano RR, Demos SG, Galland P, Gayen SK, Guo Y, Ho PP, Liang X, Liu F, Wang L, Wang QZ, and WB Wang. 1998. "Time-resolved and nonlinear optical imaging for medical applications," *Annals of the New York Academy of Science*, 838: 14-28.
40. Jolesz FA. 1998. "Interventional and intraoperative MRI: A general overview of the field," *Journal of Magnetic Resonance Imaging*, 8(1): 3-7.