Contents

Introduction ................................................................................................................................ 3

Radiotherapy Physics ................................................................................................................. 5

Tissue Substitutes X-Ray Phantoms, Ultrasound Phantoms ................................................. 6

Imaging Physics ............................................................................................................................ 7

Low Angle X-Ray Scattering ....................................................................................................... 8

Clinical Microvascular Studies .................................................................................................. 9

Physiological Measurement Velopharyngeal Function ............................................................... 10

Physiological Measurement
Studies in Respiration in Adults and Neonates Control of Breathing .................................. 11

Physiological Measurement
Respiration ........................................................................................................................................ 12

Physiological Measurement
Studies in oxygen delivery and utilisation ................................................................................... 13

Clinical Application of Microwaves ............................................................................................ 14

Academic Links ............................................................................................................................ 15
Introduction

Clinical physics and engineering support has been in existence for over sixty years at St Bartholomew’s Hospital and The Royal London Hospital. During that time, research and development applied to the care and treatment of patients has always been an essential activity.

The Physics Department at St Bartholomew’s Hospital was established by George Innes, M.B.E., who in 1936, together with one technician, Thomas Crichton, installed the first 1 MV x-ray unit to be used in the world for therapeutic purposes. Under his guidance, the department steadily expanded and undertook duties in the developing field of medical radiation physics. Important advances were made in radiotherapy physics, nuclear medicine and radiation safety. After George Innes retired in 1970, Dr Charles Greatorex was appointed to take charge of the re-named Radiation Physics Department, with responsibilities for radiotherapy physics and radiation safety. Dr Greatorex left the department in 1974 and his post was filled by Dr William Liversage who had special interests in radiotherapy physics and radiobiology. During 1986 he retired and was succeeded by Dr David R. White. In later years the department’s research and development work in imaging physics and radiation safety has been strengthened.

In 1964, Bernard Watson set up the Department of Medical Electronics and soon began an extensive and vigorous research programme covering many aspects of physiological measurement. While the development of diagnostic methods was the main activity, more recently the emphasis shifted towards therapy. Research, design and development were strengthened by the close relationship between the College and Hospital parts of the department. Much of the work was written up as PhD or MSc theses and many ex-students have gone on to make significant contributions in medical physics.

Notable Events

1936  Installation of 1 MV radiotherapy x-ray unit, the first megavoltage unit in the world to be used for treatment purposes.
1956  Discovery of errors in UK primary radiation measurement standards.
1957  Introduction of film badge personnel monitoring services.
1960  Development of lead compensators for radiotherapy treatments.
1961  Installation of 15 MeV linear accelerator for x-ray and electron treatments.
1962  First cobalt-60 eye applicators developed for the treatment of retinoblastoma.
1969  Initial work on tissue substitutes and phantoms.
1970  Processing of electroencephalogram by minicomputer.
1972  Measurement of the urethral pressure profile.
1976  Vectorcardiology analog computer developed.
1980  Alimentary pH profile measured by radio-telemetry capsule.
1986  Real-time analysis of intra-cardiac signals.
1987  Introduction of stereotactic brain treatments.
1993  Publication of The Physics and Dosimetry of Therapy Electron Beams.
1995  Study of nuclear magnetic resonance characterisation of thyroid and breast tissue completed.
1996  Study of velopharyngeal function in cleft palate patients completed.
1999  Study of tissue substitutes and phantoms in medical ultrasound published.
2002  EPSRC funded research into high frequency ultrasound imaging and associated phantoms.
2002  IMRT research begun in Radiotherapy Physics.
Overseeing all of the physics work at St Bartholomew's Hospital was Joseph Rotblat, Nobel Laureate Nobel Peace Prize, 1995, who was later Professor of Physics at the Medical College of St. Bartholomew's Hospital from 1949-1976. In 1981, the department moved from offering an ad hoc instrument repair service to providing a comprehensive equipment management programme, supported by dedicated, trained technical and scientific staff. In 1994 this group merged with The Royal London Hospital's Medical Equipment Department to form Clinical Equipment Management, the largest section of the Clinical Physics Group.

The Medical Physics Department was established at The London Hospital in 1943 by Dr John Read. During his three years at The London, Dr Read continued his pioneering work in the field of x-ray dosimetry. In 1946 Dr Lloyd Kemp, O.B.E., became head of department and for the next twenty years built up the medical physics services to The London. His research interests continued the department's involvement in radiation dosimetry. His expertise resulted in the exceptional achievement of the discovery of errors in the primary UK and US measurement standards for which he received the prestigious Röntgen Prize. From 1966-1975 Dr Montague Cohen was head of department and the innovative development work on radiotherapy physics continued. In 1975 Dr Stanley Klevenhagen became Chief Physicist and specialised in the physics of electron dosimetry. He became the author of many key papers and books on the subject of radiation physics applied to radiotherapy.

The Physics and Medical Electronics/Equipment Management Departments at the two hospitals were merged into a single Clinical Physics Group in 1994 and Dr David White was appointed Chief Physicist. At present the research work and postgraduate teaching activities covers Radiation Physics, Imaging, Physiological Measurements, Tissue Characterisation and Therapy Treatments. This is undertaken by nine full time funded pre and post doctoral researchers, supported by consultant grade scientists and a Lead Investigator.

The research activities of the Clinical Physics Department are compatible with the aims of the Barts and The London NHS Trust and support the Trust's objectives in the provision of healthcare to the community. In this document the research work of the Group is described. Details of the Academic Links in the UK, continental Europe and North America are given in the Appendix.

British Institute of Radiology awards made to staff:

<table>
<thead>
<tr>
<th>The Röntgen Prize</th>
<th>Stanley Melville Award</th>
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<tr>
<td>1936 Dr L A W Kemp</td>
<td>1960 Dr M Cohen</td>
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<tr>
<td>1973 Dr M Cohen</td>
<td>1975 Dr S Klevenhagen</td>
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<tr>
<td>1990 Dr P N Plowman and Physics Team</td>
<td>The Barclay Prize</td>
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<tr>
<td>1995 Dr S Klevenhagen</td>
<td>1981 Dr D R White</td>
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Radiotherapy Physics

The development of radiotherapy physics from the early years of this century was successful due to the close relationship between Hospital and Medical College. At St Bartholomew’s Hospital, Frank Lloyd Hopwood as Professor of Physics initiated the development of interstitial radium, radon seeds in ocular tumours and, in conjunction with George Innes, the introduction of the first clinical one million volt x-ray machine. At The Royal London Hospital, the Physics Department contributed to the early understanding of radiobiology and under the direction of Lloyd Kemp and Montague Cohen, developed the UK therapy level secondary standard dosimetry system which is in use to this day. The outstanding work of Stanley Klevenhagen in electron dosimetry is the current standard by international acclaim. Under the current management the research and development work is closely allied to clinically based projects.

Current Research

- Portal image analysis for complex radiotherapy.
- Conformed stereotactic radiotherapy with a multi-leaf collimator.
- Verification of high dose-rate (HDR) brachytherapy.
- Inverse planning and intensity modulation in multiple conformal radiotherapy.

Researchers

- Consultant and Senior Clinical Scientists - 3

Achievements

- Introduction of the first linear accelerator based stereotactic radiotherapy in the UK.
- Paediatric and ocular brachytherapy.
- Fundamental dosimetry of electron beams and electron solid water phantoms.
- Homogeneity of dose in total body irradiation.
- Conformal radiotherapy using dynamic wedge and multi-leaf collimation.
- Intensity modulation using partial transmission blocks in cranial irradiation.

Key Papers


Tissue Substitute

X-Ray Phantoms, Ultrasound Phantoms

The study of tissue characterisation with respect to radiation interactions began at St Bartholomew’s Hospital over 25 years ago. Following the PhD work of White (1974) and Constantinou (1978), the applied research has concentrated on the production of high precision tissue substitutes and phantoms for use in radiotherapy and diagnostic radiology (mammography, computed tomography and dental radiology). In recent years the study has been extended to medical ultrasound and other non-ionising radiations.

Current Research
- Tissue substitutes which simulate pathological body tissues.
- Materials for use with medical ultrasound and microwaves.
- High frequency ultrasound tissue mimicking material.

Researchers
- Consultant and Clinical Scientists - 2

Achievements
- Development of two formulation methods.
- Study of body tissue composition.
- Epoxy resin-based tissue substitutes.
- Formulation of solid water substitute for radiotherapy dosimetry.
- Manufacture of dosimetric and imaging phantoms.
- Leading role in producing four definitive ICRU Reports.
- EPSRC grant to ultrasound tissue substitutes (2004).

Key Papers


Imaging Physics

The department has wide experience in the evaluation of all types of medical x-ray imaging equipment and security detection devices, and in the design of phantoms and test tools. The main research interests are image quality evaluation and phantom design, radiation dosimetry, methods of tissue characterisation and the use of information from scattered radiation fields, using both experimental techniques and computer modelling.

Current Research
- Image quality and dosimetry in mammography, digital radiology and computed tomography.
- The assessment of the radiation safety and image quality of security x-ray systems.

Researchers
- Consultant and Clinical Scientists - 5

Achievements
- Development of imaging test tools for medical and non-medical systems.
- Development of testing protocols for digital systems.

Key Papers


Low Angle X-ray Scattering

A research x-ray laboratory specialising in Low Angle X-ray Scattering (LAXS) for diagnostic and industrial radiographic applications was established following a research grant from the Home Office to investigate the use of LAXS as a means of security inspection. Materials within extended objects such as suitcases may be located and characterised according to their unique diffraction profiles or "signatures". The application of this technique to in-vivo patient measurements is also being investigated. All aspects of the system are being developed including the building and geometric optimisation of the LAXS spectrometer, rapid data analysis techniques and alternative detector systems. The research is carried out in collaboration with University College London. In addition to LAXS the facility is used for x-ray fluorescence and x-ray attenuation measurements for clinical applications. At present we have nolaboratory space and the equipment has been relocated to UCL.

Research time have been given at ELETTRA, a European synchrotron radiation research facility, on the SYRMEP beamline. Investigations include diffraction imaging and tomography of breast tissue samples.

Current Research
- Rapid identification of restricted materials for security screening.
- Characterisation of urinary calculi.
- Diffraction imaging and tomography of breast samples.

Researchers
- Consultant and Senior Clinical Scientists - 3

Achievements
- Research grant (£170,000) from Home Office (including one full-time research post) for in-depth evaluation of LAXS for security applications.
- Development of a research LAXS spectrometer for rapid interrogation of extended objects, using a CdZnTe array and multivariate analysis.
- Development of a low angle scattering technique for the identification of urinary stone type in vivo.

Key Papers


Clinical Microvascular Studies

The Ernest Cooke Vascular and Microvascular Unit was founded in 1976 as the Thermographic Unit under the auspices of the Department of Medical Electronics, with the aim of defining the place of thermography in breast disease, particularly neoplasia. Since then the Unit has been dedicated to the development of non-invasive measurement techniques for peripheral microvascular blood flow, also including capillaroscopy, plethysmography, Doppler and laser Doppler flowmetry.

Since 1998, the Unit has provided a clinical service to the Trust’s Clinical Directorates and to hospitals in the South East and further afield, embracing the use of high resolution colour duplex ultrasound and improving and expanding the portfolio of microvascular techniques. With regard to microvascular studies, a recent innovation is the incorporation of a miniaturised high resolution CCD into an optical probe housing a wide range of magnifying lenses, making possible the use of capillaroscopy on all the cutaneous and reachable mucous surfaces of the body. A recent development of venous duplex ultrasound aims at defining the enhanced thrombogenic activity prior to the onset of Deep Vein Thrombosis.

Today, the Unit has research activities embracing vascular and microvascular topics as well, spanning from the flow dynamics of arterio-venous fistulae in patients undergoing dialysis to the effects of nitric oxide on skin blood flow.

Current Research

- Blood flow characteristics preceding venous thrombosis.
- Flow dynamics of A-V fistulae assessed by colour duplex ultrasound
- Development and application of a nitric oxide (NO) generation/delivery system in the topical treatment of ischaemia and concomitant infection.
- Significance of carotid artery stenosis in ischaemic heart disease.
- Elaboration of the microcirculatory function in systemic inflammation and sepsis.

Researchers

- Clinician, Senior Clinical Scientists - 2, Vascular Technologist - 1, Physicist - 1

Achievements

- Development of the use of prostanoids in the management of Raynaud's syndrome.
- The lag curve in Raynaud's Phenomenon in response to mild cold stress.
- The behaviour of the finger- and toe-pulp arteriovenous shunts.
- Development of a Nitric Oxide generating system.
- Definition of pre-thrombotic state in Deep Vein Thrombosis.

Key Papers


Physiological Measurement

Velopharyngeal Function

The investigation of speech impairment in children due to the presence of a cleft palate has required the development of specialised measurement techniques. Physiological measurements of velopharyngeal function during speech were initially instigated in conjunction with The Speech Therapy Department of The London Hospital in 1990. Since that time the development of investigative techniques have broadened to encompass acoustic measurements (Birch et al., 1991; Birch, 1996) and videofluoroscopic image analysis (Birch et al., 1994; Birch, 1996). Collaborative clinical trials and the routine clinical measurements are also undertaken in conjunction with other major plastic surgery centres.

Current Research
- Comparison of effect on speech of various surgical cleft repair techniques.
- Phase relationship between glottal wave and velopharyngeal closure.
- Additional velopharyngeal measurements derived from image analysis.
- Assessment of measurement uncertainties.
- Investigation of the biomechanical properties of soft palate tissue.
- Mathematical modelling of the soft palate.

Researcher
- Consultant Clinical Scientist (part-time), PHD student.

Achievements
- Development of a nasal resonometer for the assessment of hyper-nasal and hypo-nasal speech.
- New measurement techniques for the evaluation of velopharyngeal function.
- Intercomparison of surgical techniques.
- Three year study of surgical efficacy in patients undergoing cleft palate re-repair.

Key Papers


Physiological Measurement

Studies in Respiration in Adults and Neonates Control of Breathing

Breathing is accurately regulated throughout life without need for conscious control. This is being studied by applying the concepts of engineering control theory to the analysis of respiratory measurements and also to the analysis of mathematical models.

Current Research

- Mathematical modelling of the respiratory control system with particular reference to neonates. It is thought that the patterns of breathing reflect the requirement to achieve adequate gas exchange while minimising the work of breathing. A set of differential equations have been derived which represent a model of the essential features of the respiratory system and these are being analysed.
- Interpretation of physiological recordings from babies using time series analysis. (Respiration, oesophageal pressure).
- Development of techniques for the non-invasive assessment of the mechanics of the respiratory system in adults (Forced oscillation technique for respiratory impedance, Optical methods for the visualisation of air flow from the nose.)

Researcher

- Senior Clinical Scientist

Achievements

- Identification of characteristic changes in the patterns of breathing in the first six months of life, indicating maturation of the underlying control system.
- Identification of possible causes of instability in breathing patterns by means of mathematical models.
- A prediction from the model studies that Periodic Breathing could actually be beneficial in some cases as it could actually raise average arterial oxygen saturation. Demonstration of the minimisation of work of breathing in babies during the first week of life using records of breathing and oesophageal pressure.
- Investigations of breathing and metabolism in relation to temperature control in the first three months of life.
- Establishment of thermoneutral temperature ranges for clothed neonates between one and three months of age.

Key Papers


Physiological Measurements

Respiration

Studies in respiration currently concentrate on two principal areas, the measurement of respiratory function in children and adults and the assessment of nasal obstruction.

Current Research

- Development of techniques for the non-invasive assessment of respiration.
- Use of the forced oscillation technique for the study of respiratory mechanics.
- Development of non-contact techniques for the assessment of nasal function.
- Investigations into perception of nasal obstruction, pre- and post-surgery.
- Modelling airflow in the nasal cavity during tidal breathing (collaboration with Dept. of engineering, QMUL).

Researcher

- Senior Clinical Scientist

Achievements

- Identification of characteristic changes in the patterns of breathing in the first six months of life, indicating maturation of the underlying control system.
- Identification of possible causes of instability in breathing patterns by means of mathematical models.
- A prediction from the model studies that Periodic Breathing could actually be beneficial in some cases as it could actually raise average arterial oxygen saturation. Demonstration of the minimisation of work of breathing in babies during the first week of life using records of breathing and oesophageal pressure.
- Development of a quantitative measurement of nasal function using infrared thermography.
- Establishing ranges of normal values of respiratory impedance in adults measured using the forced oscillation technique.

Key Papers


Physiological Measurements

Studies in oxygen delivery and utilisation

The delivery of oxygen to tissue is vital to metabolism. Measurements of blood flow and oxygenation can provide information as to the adequacy of oxygen delivery. By also measuring concentrations of oxygen binding compounds in the tissue of interest the oxygen metabolism within that tissue can be studied.

Current Research

- Monitoring of tissue viability during plastic surgery. Replanted tissue such as a free flap is at risk from vessel occlusion in the first few post-operative days. An instrument has been developed and is being used to study haemodynamic events in the tissue to give an early warning of the onset of tissue ischaemia.
- Data recorded from surgical flaps are being used to develop algorithms for automatic identification of impending flap failure.
- Optical techniques are being used to study global and cerebral oxygen metabolism simultaneously during cardio-pulmonary bypass surgery.
- Development of optical techniques to study healing of ulcers of the lower limbs.

Researcher

- Senior Clinical Scientist

Achievements

- Recordings of haemodynamic events in human free flaps during surgery using a custom designed optical probe.
- Demonstrated potentially harmful falls in oxygen delivery during periods of hypoperfusion at normothermia and mild hypothermia.

Key Papers


Microwave Antenna Development

The use of microwave radiation delivered endoscopically to treat cancerous tissue was first investigated in conjunction with the Gastroenterology Department at The Royal London Hospital in 1990. The production of an endoscopic microwave system (Kalabakas et al., 1993) has demonstrated the feasibility of using microwaves in the upper gastrointestinal (GI) tract.

The system has been refined enabling uniform heating by the miniature microwave antennas within a muscle-equivalent phantom. The antennas have been designed to investigate their potential use in the treatment of Barrett’s oesophagus. The aim is to controllably heat the Barrett’s tissue to cytotoxic temperatures whilst sparing the deeper underlying healthy tissue.

Current Research
- To incorporate multiple temperature measuring devices within the system.
- To provide in vivo thermal model of the microwave device including generic vasculature.
- Study the cytotoxic effect of the device on tissue with treatment parameters (temperature and time).
- Develop planning system, which allows the effect of the treatment to be modelled against the treatment parameters.

Researcher
- Clinical Scientists - 2

Achievements
- Awarded £100K "New and Emerging Applications of Technology" in 2001 from Dept of Health with £40 extension in May 2004.
- Awarded Spiers’ Prize - IPEM Annual Conference 2003.
- UK Patent application PCT/GB03/002948 'Hollow Organ Probe'.
- Development of endoscopic delivery system to deliver microwave energy to the upper GI tract.
- Characterisation of the thermal distributions produced by helical antennas in muscle-equivalent phantoms at 915 MHz.

Key Papers


Academic Links

United Kingdom
Aberdeen Royal Hospitals.
Addenbrookes Hospital, Cambridge.
Bristol University.
City of London University.
Guy's and St. Thomas' Medical School, London.
Homerton Hospital, London.
King's College Hospital, London.
Moorfields Eye Hospital, London.
National Physical Laboratory, Teddington.
National Radiological Protection Board, Chilton.
Southbank University, London.
The Royal Free Hospital, London.
UMDS, Guy's and St. Thomas' Hospitals, London.
University College London.
University of Dundee.
University of Kent at Canterbury.
University of Manchester. UMIST
University of Sheffield.
Rutherford Laboratories, Cambridge.

Continental Europe
"Frédéric Joliot-Curie" National Research Institute for Radiobiology and Radiohygiene, Budapest, Hungary.
University of Utrecht, Holland.
GSF - Forschungszentrum für Umwelt und Gesundheit, Neuherberg, Germany.
International Atomic Energy Agency (IAEA), Vienna, Austria.
Institute of Biomedical Technology (INBIT), Patras, Greece.
Université Catholique de Louvain, Brussels, Belgium.
University of Patras, Greece.

USA
International Commission on Radiation Units and Measurements, Bethesda.
Memorial Sloan-Kettering Cancer Center, New York.
University of Wisconsin, Madison.