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Emma Bowers (Freeman Hospital, Newcastle upon Tyne) recently completed a PhD with assistance from the IPEM Research Training Fellowship. As a thank you, she has summarised her research and findings in this article.

Since 2000 I have worked at the Freeman Hospital, as a Clinical Scientist, in the Clinical Instrumentation and Physiological Measurement section of the Regional Medical Physics Department. In 2003 I successfully applied for the first IPEM Research Training Fellowship. The Fellowship enabled me to be bought out of my job part time so that I could pursue a research degree. In this article I would like to summarise my PhD project, ‘Investigation of the interactions between breathing, beat by beat changes in RR intervals and beat by beat changes in systolic pressure levels’, for the readers of Scope.

BACKGROUND TO THE PROJECT
Our blood pressure is constantly changing due to internal and external influences. Blood pressure can be measured continuously yet non invasively using the Finapres device. The natural variations in systolic
pressure (SP) levels can easily be seen from the Finapres trace in figure 1. Our body balances these blood pressure changes through the baroreflex, by altering heart rate, stroke volume and peripheral resistance.

Changes in heart rate can be seen as varying time periods between the R waves in the ECG trace (known as RR intervals); these can easily be seen from the ECG trace in figure 1. Changes in SP levels and RR intervals are strongly modulated by breathing, as seen in figure 2. The integrity of the baroreflex is often measured by baroreflex sensitivity (BRS), the ratio of change in RR interval to change in SP level. If SP levels and RR intervals are evenly sampled in the ‘beat domain’, these derived data are evenly sampled in the ‘beat domain’ but unevenly sampled in RR intervals. A linear interpolation has to be performed so that the derived data is sampled regularly (16 Hz) in the time domain.

The sampling of the breathing signal is reduced until it is the same as the derived data. Phases and gains between both derived data sets, and breathing, were calculated in the frequency domain by cross spectral analysis, provided the coherence value between the two data sets was greater than 0.5.

To calculate the repeatability of the phase and gain, I recorded 20 normal subjects who followed regular breathing patterns, resulting in breathing rates of 4, 6, 8, 10, 12 and 14 breaths per minute, each for 3 minutes, twice on one day. Seventeen returned for a second recording session where they followed the same breathing patterns twice. To enable me to consider factors that might influence phase and gain values, further recording sessions required subjects firstly to follow different breathing patterns (resulting in asymmetrical, dual frequencies, resistive and spontaneous breathing); secondly to induce regular changes in SP levels and RR intervals, by means other than breathing, through regular hand grip, regular tilting, regular leg raising and regular mental tasks; and thirdly to follow regular breathing signals in different postures.

**RESULTS OF THE EXPERIMENTS**

The repeatability of all the gains was measured as coefficients of variation. The repeatability of baroreflex sensitivity was 20 per cent, in keeping with the current literature. Those of the gains between breathing and RR intervals, and breathing and SP levels, were established for the first time to be 25 per cent and 26 per cent, respectively. The repeatability of the phases measured as standard deviations of repeats, and established for the first time to be 20°, 21° and 27° for SP levels to RR intervals, breathing to RR intervals, and breathing to SP levels, respectively.

Breathing frequency greatly influenced all phases, and the two gains associated with breathing. Phases between SP levels to RR intervals decreased with increasing breathing frequency. Phases between breathing and RR intervals, and breathing and SP levels, increased with increasing breathing frequency. The two gains, associated with breathing, decreased with increasing breathing frequencies. The changes in phases and gains, where the two extremes of breathing frequencies were considered, are shown in figure 4.

When repeatability was calculated from subjects who breathed spontaneously, as opposed to regularly, there was a 40 per cent greater variability in phase measurements, but no significant difference in gain measurements. Different breathing patterns affected all the gains and phases in various ways. Inducing changes in RR intervals and SP levels in ways other than breathing were not as successful, and resulted in different values for the phases and gains. Posture had a strong effect on phase and gains: proceeding from a standing to supine position resulted in an increase in phase and gain between SP levels and RR interval, and a decrease in phase between breathing and RR intervals and breathing and SP levels.

**DISCUSSION AND CONCLUSIONS**

The three phases measured between breathing, RR intervals and SP levels are not independent as they are linked according to the equation below:

\[
\text{phase (SP to RR)} = \text{phase (breathing to RR)} - \text{phase (breathing to SP)}
\]

...
FIGURE 1. How the RR intervals and systolic pressure levels are derived from the ECG and the signal from the Finapres.

FIGURE 2. Breathing modulates RR intervals and systolic pressure levels.
FIGURE 3. Simple linear models.

(a) Systolic Pressure levels $\rightarrow$ simple linear model $\rightarrow$ RR-intervals

(b) Breathing signal $\rightarrow$ simple linear model $\rightarrow$ RR-intervals

(c) Breathing signal $\rightarrow$ simple linear model $\rightarrow$ Systolic Pressure levels

FIGURE 4. Changes in phase (left-hand side) and in gains (right-hand side) with the slowest and fastest breathing rates. Data are mean ± 2 SEMs.
Due to the cyclic nature in the changes of the signals, causality between these signals cannot be established.

The repeatability of the phases between breathing, RR intervals and SP levels has not been measured before, nor has that of the gains between breathing and RR intervals, and between breathing and SP levels. The repeatability of the BRS gain is in keeping with the values reported in the literature. Repeatability of the phases and gains is not good even though great care was taken to ensure the environment remained constant, and subjects followed the protocols identically.

The recording of other protocols showed that changing the breathing pattern has a large effect on the phase and gain values. These effects are great enough that, despite the poor repeatability of the measurement, significant differences can be measured. Maintaining the necessary concentration to breathe very regularly for 3 minutes is difficult. Any slight deviation from the given protocol, for example breathing in quicker than asked to, or temporarily losing concentration so as to get out of synchronisation with the requested breathing pattern for a short time, are likely to have significant effects on the measured phase offset or gain. This hypothesis is backed up by the poorer repeatability of spontaneous breathing compared with regular breathing.

In conclusion, measuring phase and gain in a repeatable way is difficult. From the results of the study so far, I am unable to recommend an ideal protocol, without further work. In the future I hypothesise that more repeatable measurements of phases and gains could be recorded from subjects in a standing position following regular breathing protocols, with models developed that can correct for the variation from the given protocol (e.g. variation in tidal volume and inspiration times, on a breath by breath level).

LONG-TERM BENEFITS

It is important to understand the baroreflex loop in healthy normal subjects and be able to record repeatable results from this group. Phase and gain between SP levels and RR intervals have been shown to be clinically relevant but can only be used for comparing large groups. This PhD has enabled us to take a step closer to understanding what affects the baroreflex loop in normal subjects. Further work is required to develop models so that some variation can be accounted for and removed. If repeatable measurements can occur then high-risk patients can be identified and managed appropriately. Ideally, these measurements could be used to detect cardiovascular problems.

ACKNOWLEDGEMENTS

I would sincerely like to thank IPEM for giving me the opportunity to complete a PhD. It will be an important and ongoing tool as I pursue my chosen career as a clinical scientist. I would also like to thank Professor Alan Murray for his supervision, and his advice and support, throughout my PhD period.
Flow dynamic analysis

D.V. Rafiroiu¹, V. Diaz-Zuccarini²,³, A.J. Narracott³, D.R. Hose³ and P.V. Lawford³ evaluate the cavitational and thrombogenic potentials of mechanical heart valves

Detailed flow dynamic analysis in the vicinity of the leaflets and the housing during the valve-closure phase (including the rebound) is of interest for the assessment of both the thrombogenic and the cavitational potential of a candidate valve. A newly-developed lumped parameter model of the left ventricle (LV) contraction and a computational fluid dynamics (CFD) representation of the fluid-structure interaction (FSI) are coupled, allowing for the investigation of the valve closure under different conditions. The platelet activation potential is related to the velocity profile in the clearance region and to the duration for which the leaflets are exposed to wall shear stress (WSS). The cavitational potential is related to the negative pressure transients at the leaflet edge and to the vorticity of the flow during valve closure and rebound.

**INTRODUCTION AND BACKGROUND TO THE ANALYSIS**

Cardiovascular engineering is one of the success stories in bioengineering. A specific example of a successful cardiovascular engineering application is the design analysis of prosthetic heart valves. Although existing techniques, including mechanical heart valves (MHV) and biological valves (BV), have stood the test of time there are still some important issues to resolve regarding thrombogenecity of MHVs and life-time duration for biological valves. Even though no new MHVs will be developed, an exact understanding of the complex mechanisms leading to thrombosis is still important, both for improving the quality of life of the patients still bearing such cardiovascular devices and for knowing exactly what to avoid with the new breed of heart valves. New endovascular techniques such as percutaneous heart valves are being developed to avoid open heart surgery with the design and implementation of these devices still in a developmental phase. The application of modelling and simulation to the study of existing and novel devices can certainly help to address these issues and significant work remains related to the assessment and behaviour of these valves under patient-specific conditions and with reference to pharmacological intervention for these patients.

More recently, CFD has emerged as a promising tool which, alongside experimentation, can yield insights of unprecedented detail into the hemodynamics of prosthetic heart valves. For CFD to realise its full potential, however, it must rely on numerical techniques that can handle the enormous geometrical complexities of prosthetic devices with spatial and temporal resolution sufficiently high to accurately capture all hemodynamically relevant scales of motion. Valve function is driven by interaction between the blood and the motion of solid valve structure. In order to examine such systems computationally, it is necessary to consider both the solid and the fluid phases simultaneously, which requires an FSI analysis. Recent computational models have used both custom and commercial codes such as ANSYS-CFX, ANSYS-Fluent and LS-DYNA. These have been applied to the study of native mitral and aortic valves, and also to determine the fluid dynamic performance of valve prostheses.

The effects of the heart, vasculature and the systemic response to the changing physiological environment are often not included within local 3D models of valve function. Multi-physics and multi-scale modelling brings new insight by allowing such interactions to be investigated in silico. The use of FSI analyses has highlighted the need for improved and interactive boundary conditions. Solutions include FSI analyses coupled with lumped parameter boundary condition models which can represent biochemical reactions at the cellular level and electro-mechanical events in the heart. Patients with mechanical heart valve implants need to be under long-term anticoagulant therapy in order to minimise problems related to thromboembolic complications. Cavitation bubble development due to the large negative pressure transients on the inflow side of the leaflet edge and their subsequent collapse may contribute to both the platelet activation and the structural damage of the valve.

In the model presented below, the fundamental design of a Saint Jude bileaflet MHV is used. In our previous studies we have simulated the dynamics of some single leaflet MHVs, with idealised geometries. Now it is for the first time that we use real bileaflet valve geometry and our decision to use this specific valve has nothing to do with the manufacturer, the design or its size. A lumped parameter model of the LV contraction and a CFD representation of the FSI are coupled to simulate the valve closure. The LV model gives a ‘more realistic’ representation of the cardiac muscle contraction, from the level of the contractile proteins up to the haemodynamics of the whole ventricle. The commercial, finite volume code (ANSYS-CFX) is coupled to the lumped parameter ventricle model through the inlet and outlet boundary conditions. The coupled model has already been tested when investigating the cavitational potentials of single and bileaflet MHVs.

**MATERIALS AND METHODS**

**THE CFD MODEL**

To build up the computer-aided design (CAD) model, an explanted 23 mm tissue annulus diameter (TAD) bileaflet valve was disassembled and three-dimensionally laser scanned. There is a strong possibility that the valve housing would have been damaged during disassembling. However, for the moment, we didn’t consider this as a critical problem because, in our model, the occluders have only one degree of freedom (the rotation) and the valve cannot be completely closed. For the established axis of rotation, a maximum rotation angle of 64 degrees has been obtained. The resulting CAD image of the assembled valve is shown in figure 1.
Considering the valve to be mounted in mitral position, the CAD model was completed with two cylindrical chambers representing the atrium and ventricle. The atrial chamber, positioned in the negative OX direction, is 24 mm in length whilst the ventricular chamber, also 24 mm in length, is positioned in the positive OX direction. For saving computational resources, only one quarter of the valve was considered in the 3D model. The model’s reduction to one quarter is allowed by the double-plane symmetry of the valve. Symmetry boundary conditions will be imposed at these planes (figure 2).

Blood was considered as an incompressible Newtonian fluid with density $\rho = 1100$ kg/m$^3$ and dynamic viscosity $\mu = 0.004$ kg/m·s. The unsteady flow field inside the valve is described by the 3D equations of continuity and momentum (1), with the boundary conditions suggested by figure 2.

$$\rho \frac{\partial u}{\partial t} + (u \cdot \nabla)u + \mu \nabla^2 u - \nabla p = 0$$

The principle used to model the fluid–structure interaction is outlined in figure 3. Each leaflet rotates under the combined effects of hydrodynamic, buoyancy and gravitational forces acting on it. At every time step, the drag, $f_d$, and lift, $f_l$, forces exerted by the flowing fluid on an arbitrary point Q of the leaflet’s surface are reduced to the centroid, G. The total contribution of drag $F_d$ and lift $F_l$ are added to the difference between the gravitational and buoyancy forces.

The condition for the conservation of the kinetic moment is imposed, resulting in the dynamic equation (2) that describes the motion. In equation (2), $d\theta$ represents the leaflet’s angular step, $\Delta t$ is the time step, $\omega_{old}$ is the angular velocity at the beginning of the current time step and $M$ is the total moment acted on the leaflet from the external forces. The moment of inertia of each leaflet is $I = 7.21$ g.mm$^2$.

$$d\theta = \omega_{old} \Delta t + \frac{M}{2I} dt^2$$

As there is speculation that vortexes are likely to occur after the first impact between the leaflet and the valve housing, the rebound motion is also modelled. When, within the current time step, the angular position exceeds $\theta_{end} = 63.7$ degrees, corresponding to a minimum distance between the leaflet’s periphery and the housing, a virtual torsion spring with constant $C$ is suddenly twisted between the current position and $\theta_{end}$. The torque exerted by the spring is added to the gravitational force, thus reversing the leaflet’s rotation. The dynamic equation changes accordingly:

$$d\theta = \omega_{old} \Delta t + \frac{M}{2I} dt^2 - C \frac{(\theta_{old} - \theta_{end})}{2I} dt^2$$
According to equation (5), displacements of every point \( Q \) from the surface of the leaflet are calculated as a function of the distance to the centre of rotation, \( r \), its angular coordinate at the previous time step, \( \theta \), and the current angular step, \( d\theta \). The current linear displacements are added to the ‘old’ values for each coordinate and the moving boundary is displaced accordingly.

THE LEFT VENTRICLE MODEL TO SHOW CONTRACTION

To represent the LV contraction, a complex boundary condition is used. Figure 4 shows the sub-levels of organisation of the ventricle that were taken into consideration to give a ‘more physiologically realistic’ model of its contraction.

The connection between the LV model and the valve model is also illustrated in figure 4. The LV model is connected to the valve model through the outlet boundary of the latter (the output model). Contraction in the cardiac muscle is described at a number of levels, starting from the level of the contractile proteins (actin and myosin), following a hierarchical path, from the microscopic level up to the tissue (muscle level) and to the organ (LV) level, to finally reach the haemodynamic part of the LV and its arterial load. Contraction of the LV provides a growing pressure to the outlet boundary of the valve model, at a variable rate. The LV pressure rate is controlled by the biochemical activity of the sarcomeres. A constant pressure source is applied at the inlet boundary of the valve model (input model). Complete details of the formulation of the model can be found in LeFevre, LeFevre and Couteiro.12

RESULTS

The model of the LV contraction allows for changing various parameters. By modifying the chemical constant of the sarcomere, two ventricular pressure rates have been set up thus simulating two different heart beats, a weak one and a 30 per cent stronger one. For further details about the implementation of the left ventricle model, please refer to Diaz-Zuccarini et al.13 The whole movement of the valve was separated into two distinct phases: the first being the approaching phase and the second is the rebound phase.

THE FIRST PHASE OF CLOSURE: THE APPROACHING PHASE

The first phase of the valve closure, named the ‘approaching phase’, is the longest. It refers to the movement of the leaflets from the fully closed position until their first impact against the housing, covering 63.7 degrees. The actual movement of the leaflets starts at about 16 ms after the initiation of the contraction, when the moment exerted by the hydrodynamic forces exceeds the moment created by the gravity force. Figure 5 shows both the angular position and the peripheral velocity histories, for both simulated contractions. The approaching phase lasts for a little bit less than 35 ms. Figure 6 shows the corresponding ventricular pressure and ventricular pressure rate histories.
Attempting to correlate cavitation to the maximum LV pressure rate \(\left(\frac{dp_{ventricle}}{dt}\right)\), early studies suggested the threshold of 2000 mmHg/s (266,645 Pa/s), above which cavitation is likely to occur.\(^{14}\) Our results indicate that, by the end of the approaching phase, \(\frac{dp_{ventricle}}{dt}\) reaches a maximum value of about 8000 mmHg/s (1,066,579 Pa/s) and the angular velocity of the leaflets reaches almost 500 rad/s, thus indicating a potential cavitation risk.

**THE SECOND PHASE OF CLOSURE: THE REBOUND PHASE**

When seeking for evidence of the thrombogenic and cavitation effects, we have to look pre-eminently at the end of closure, namely at the rebound. This is the second phase of the valve closure. It begins at the moment of the first impact of the leaflets against the housing and lasts until the valve completely stops, reaching the fully closed state. During the rebound phase, each occluder performs an oscillating (bouncing) damped motion, until they completely stop. The amplitude and the damping rate of the bouncing motion depend on the elasticity of the surrounding tissue of the valve. The elasticity of the surrounding tissue is modelled by the constant \(C\) of the virtual spring.

To investigate the effects of the elasticity of the soft tissue surrounding the valve’s housing, three different values have been given to the elastic constant of the virtual spring (\(C = 0.5, C = 0.75\) and \(C = 1\ Nm/dgr\)). Figure 7 shows the position histories of one of the two leaflets, corresponding to the three different values of the constant \(C\), in both the weak and the strong contraction case.

The first value of the elastic constant simulates a weak spring, or a soft surrounding tissue, whilst the last value simulates the strongest spring, or stiffer surrounding tissue. According to Hooke’s law, the spring with the lowest value of the elastic constant (elastic modulus of the surrounding tissue) is easier to compress than the one with the largest value. The deformation of the spring is produced by the kinetic moment of the total arrested mass of the occluder and the column of the fluid behind it. During its deformation, the torsion spring stores a certain amount of elastic deformation energy:

\[
E = \frac{1}{2} C \delta \theta^2 = \frac{1}{2} \frac{M^2}{C}
\]

By the end of its deformation, the spring releases this energy, returning it to the system. For the same value of the driving moment \(M\), the spring with the lowest value of the elastic constant accumulates the highest elastic deformation energy. This amount of energy is partially converted into kinetic energy of the rotating occluder as shown here:

\[
E_{\text{rot}} = \frac{1}{2} (1 + I_{\text{arr}}) \omega^2
\]

where \(I_{\text{arr}}\) is the moment of inertia of the arrested mass. The rest of the elastic deformation energy released by the spring is converted into kinetic and potential energy of the fluid. This explains the strongest rebound found in the case of the lowest value of the elastic constant of the surrounding tissue.
Now looking closer at the first rebound, the strongest, three successive phases can be inferred:

- The first one, called the elastic deformation phase, begins at the moment when the spring gets into action, lasting until its complete deformation. Both the occluder and the additional mass are rapidly arrested while the occluder keeps its forward movement.

- During the second phase of the first rebound, called the properly rebound phase, the previously-stored elastic deformation energy is released, pushing the occluder backward. Within approximately 10 µs the occluder reverses its movement then decelerates, recovering its forward movement. Figure 8 illustrates the reversal of the occluder’s motion for the strong contraction, showing that the stiffer the surrounding tissue, the higher the rebound moment and the faster the reversal is. For the weak contraction, the situation looks pretty much the same, the only difference being the higher closure velocity.

- During the third phase of the first rebound, called the recurrence phase, the occluder recovers its forward movement and the conditions favourable to cavitation are maintained by the vortexes occurred on the atrial side of the occluder, precisely where they have been visualised experimentally. Figure 10 shows the maximum vorticity history, at the surface of the occluder, during the first rebound, for the strong contraction case.

From the point of view of the haemolytic potential, the most critical parameter is the WSS. Figure 11 shows the maximum WSS history, $\tau_{\text{max}}(t)$, at the surface of the occluder, during the rebound phase. Even though the WSS reaches relatively high values, the haemolytic potential of the valve is still low. This is because $\int \tau_{\text{max}}(t) dt < 3.5 \text{ Pa} \cdot \text{s}$, the value suggested as indicative of platelet activation.\(^{15}\)

As indicated in figure 11, the areas under the WSS versus time curves increase with the stiffness of the surrounding tissue. That increases the haemolitic potential of the valve too but, in any of the simulated scenarios, the value of the integral did not exceed the critical magnitude of 3.5 Pa·s.

As far as the cavitational potential is concerned, our results have shown that the dominant factor, the value of the negative pressure at the surface of the occluder, also increases with the stiffness of the surrounding tissue. However, the second factor facilitating the occurrence of cavitation, the vorticity, has a slightly different behaviour. While in the case of a weak contraction the maximum vorticity decreases with the stiffness of the ventricle, in the case of a strong contraction it increases.

Returning to the global parameters of the valve’s dynamics, the amplitude of the rebound increases with the intensity of the contraction, especially when the surrounding tissue of the valve is stiff.

![FIGURE 9](image9.png) The maximum negative pressure at the surface of the occluder, during the first rebound, for the strong contraction.

![FIGURE 10](image10.png) The vorticity at the surface of the occluder, during the first rebound, for the strong contraction.

![FIGURE 11](image11.png) Maximum WSS versus time plot at the surface of the leaflet for the strong contraction.
CONCLUSIONS AND FUTURE WORK
It worth noting that the implemented model still has some drawbacks, especially relating to the incomplete closure of the valve. This is due to some features of the modelling methodology (a small gap is needed to allow for the deformation of the torsion spring) and to the limited number of degrees of freedom of the system (in the final phase of its closure, the occluder slides in contact with the hinges).

However, for highly resilient impacts (stiff surrounding tissues) the model accurately simulates the valve dynamics and correctly evaluates its cavitational and haemolytic potentials. As far as the rebound model is concerned, the solution proposed for allowing the valve to close properly is to move the torsion spring between the occluder and the fully open position and start twisting it during the approaching phase.

So, we may conclude that for the highly resilient simulated impacts, our findings quantitatively confirm the intuitive fact that the stronger the contraction and the stiffer the tissue surrounding the valve, the greater its cavitational and haemolytic potentials are.

Nevertheless, in order for a study to become more eloquent, a few successive steps are recommended:

- Resuming the simulations for a few more intensities of the ventricular contraction and checking for the effects of an increased ventricular pressure rate on the WSS values at the surface of the occluder;
- Resuming the simulations for different sizes of the valve and trying to scale and parameterise the model;
- Rebuilding the model, based on a different rheological model of the fluid, much closer to the one of blood;
- Replacing the simple cylindrical models of the ventricular and atrial chambers with 3D homeomorphic models and adding the electromechanical activity of the heart to its multiscale model;
- Implementing a two-phase model of the blood flow through the valve to better emphasise and localise the cavitational formations;
- Increasing the number of degrees of freedom for the occluders, thus allowing them to perform complex motions and extending the same modelling methodology to other MHV designs.

REFERENCES


ACKNOWLEDGEMENTS
The work presented in this paper was partially funded by the Romanian University Research Council and the European Commission, [Marie Curie Intra-European Fellowship: Project CARES]. It was supported throughout the simulation phase by the Laboratory of Medical Physics and Clinical Engineering from the University of Sheffield and by the ANSYS Europe division. The authors wish to thank to Dr Jan Jones and Dr Justin Penrose (ANSYS-CFX) for constructive advice.
Ad space
The EU-funded project EMIT was a follow up of the project EMERALD, currently used in more than 60 countries around the world. While EMERALD developed e-training materials for the physics of x-ray diagnostic radiology, nuclear medicine and radiotherapy, EMIT developed e-training materials for the physics of ultrasound and magnetic resonance imaging. These materials are on two CDs, each including a teaching database of images and training tasks. The tasks are built in accordance with the IPEM competencies, increasing their depth and breadth. Both the images and the text are combined in e-workbooks with a user-friendly web interface.

**DIAGNOSTIC ULTRASOUND IMAGING PHYSICS**

The training tasks in the Diagnostic Ultrasound Imaging Physics e-Workbook are grouped into the following chapters:

- Introduction to ultrasound systems, basic physics.
- Introduction to Doppler ultrasound.
- Introduction to clinical instrumentation.
- B-mode ultrasound. Principles and factors affecting image quality including phantom measurements.
- Spectral Doppler continuous and pulsed wave systems – principles and implementation.
- Colour flow methods – principles and implementation.
- M-mode – principles and implementation.
- Safety of ultrasound, standards and measurement.
- Measurement of total acoustic power.
- Measurement of acoustic pressure and intensity.
- Quality assurance – B-mode standards and techniques.
- Quality assurance – Doppler/colour Doppler techniques.
- Ultrasound image storage.
- Blood flow and Doppler measurement.
- Transmission techniques (ToF, attenuation, f-dependent attenuation).
- Contrast agents, physics, clinical use and safety.
- 3D ultrasound, methods, applications, QA.
- ‘New techniques’ in ultrasound imaging.
- Purchasing, specification, evaluation and maintenance.
- General medical applications.
- Small parts applications.
- Obstetrics applications.

**MAGNETIC RESONANCE IMAGING PHYSICS**

The training tasks in the Magnetic Resonance Imaging Physics e-Workbook are grouped into the following chapters:

- Getting acquainted with available pulse sequences.
- Designing and manufacturing a gel phantom for investigation of MRI signal and contrast.
- MRI signal and contrast using basic pulse sequences. Influence of tissue and pulse-sequence parameters.
- Image quality parameters (signal-to-noise ratio, field-of-view, bandwidth, spatial resolution, etc.).
- Basic k-space properties

Slavik Tabakov [EMIT and EMITEL Coordinator] describes two electronic learning and training projects developed by the EMITEL Consortium.

**FIGURE 2 [LEFT].** The UK EMIT team with the Leonardo da Vinci Award. Standing from left to right: L. Blache, C. Lewis, S. Tabakov, A. Simmons, C. Deane, D. Goss; sitting: V. Tabakova, G. Clarke, V. Aitken [missing from the photo is Prof. Colin Roberts]. All are from King’s College London and King’s College Hospital NHS Foundation Trust.
EMITEL included IOMP (the International Organization for Medical Physics) as a partner, again the first such project for the organisation.

**EMITEL PROJECT**

The EMITEL project aims to develop an Internet-based tool (e-Encyclopaedia EMITEL), which will be freely available to all colleagues. The project builds up on the original EMIT CD-based Dictionary of Medical Imaging. This first phase of the project (the dictionary) is almost ready. It cross-translates medical physics terms between each of its languages (currently English, French, German, Swedish, Italian, Spanish, Portuguese, Polish, Thai, Hungarian, Estonian, Lithuanian, Latvian, Czech, Romanian, Greek, Turkish and Arabic). Another six languages are in preparation for inclusion soon (Persian, Bengali, Malay, Bulgarian, Slovenian and Chinese). The advanced work-in-progress of the dictionary can be accessed from: www.emitdictionary.co.uk.

Extended demos of all e-workbooks can be viewed on the website www.emerald2.eu. The demo includes the extended EMIT guide and some 20 pages with training timetables (all of the tasks with indicative time for their performance to acquire specific competencies).

**AWARD-WINNING TRANSLATOR**

The results of the EMIT project also include a CD-based translator of medical physics (imaging) terms into five languages. This innovative project was awarded with the inaugural EU prize for vocational education – the Leonardo da Vinci Award (figure 2). This was not only a great success for our e-learning projects, but also promoted medical physics at a very high level.

EMIT project partners were from King’s College London (KCL, Contractor), King’s College Hospital NHS Foundation Trust, University of Lund, Lund University Hospital, University of Florence, Hospital Albert Michallon Grenoble and the European Federation of Organisations for Medical Physics (EFOMP). This was the first EU project of EFOMP as an institution and has paved the way for further international projects and funding. Similarly, the newest project EMITEL included IOMP (the International Organization for Medical Physics) as a partner, again the first such project for the organisation.

**FIGURE 1 [RIGHT].** Graphical interface (print-screen) of the EMIT Image Database CD-ROM with ThumbPlus! browser – sample from the MRI module (example of assessment of magnetic field homogeneity). After the visualisation of a thumbnail some image processing functions can be applied and saved (example of application of image filtering).

- Investigation of advanced pulse sequences.
- Image artefacts in MRI.
- Properties of contrast agents in MRI.
- MR angiography (MRA) and flow quantification. Pulse sequences and evaluation (MIP, MPR, etc.).
- Pulse sequences and evaluation routines in MR spectroscopy (MRS).
- Overview of clinical applications.
- Comprehensive quality control/quality assurance (QC/QA) program for MRI and MRS.
- Safety issues regarding personnel and staff. Guidelines, normal policy and legislation.
- Patient safety. Guidelines, normal policy and legislation.
- Safety regarding surrounding equipment and implants: methods for testing the MR compatibility of various devices with respect to ferromagnetism (translational forces and torques), heating, image artefacts, etc.
- Commissioning and purchasing routines.

**AWARD-WINNING TRANSLATOR**

The results of the EMIT project also include a CD-based translator of medical physics (imaging) terms into five languages. This innovative project was awarded with the inaugural EU prize for vocational education – the Leonardo da Vinci Award (figure 2). This was not only a great success for our e-learning projects, but also promoted medical physics at a very high level.

EMIT project partners were from King’s College London (KCL, Contractor), King’s College Hospital NHS Foundation Trust, University of Lund, Lund University Hospital, University of Florence, Hospital Albert Michallon Grenoble and the European Federation of Organisations for Medical Physics (EFOMP). This was the first EU project of EFOMP as an institution and has paved the way for further international projects and funding. Similarly, the newest project EMITEL included IOMP (the International Organization for Medical Physics) as a partner, again the first such project for the organisation.
words and is aimed at an audience above MSc level. To enhance the educational value of EMITEL, most articles include images, graphs, examples and other additional information. The entries are grouped into seven categories: physics of x-ray diagnostic radiology; physics of nuclear medicine; radiotherapy; magnetic resonance imaging; ultrasound imaging; radiation protection, and general terms.

**EMITEL WEBSITE**

A special web database and website were designed to handle the EMITEL e-Encyclopaedia. The website includes two search engines; one allowing searches into multilingual terms (titles of the entries), and the other one searching inside the full text of the articles (in English). Additionally the project developed a Content Management System (CMS), which will allow, in the future, adding new terms, expanding the existing term entries, editing of entries, etc. This way EMITEL will serve the profession as a refereed web tool.

EMITEL project partners are King’s College London (Promoter and Coordinator), King’s College Hospital NHS Foundation Trust, University of Lund, Lund University Hospital, University of Florence, AM Studio (a software company) and the IOMP. EMITEL is financially supported by the EU Leonardo programme.

**INTERNATIONAL COLLABORATION**

At present more than 200 colleagues from 35 countries are working on EMITEL. An International/European Conference on EMITEL was recently organised by King’s College London and took place in the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, in October 2008. The conference was attended by invited delegates from 22 countries, who formed a network aimed at the future expansion and update of the EMITEL Encyclopaedia and Dictionary. The conference delegates (see figure 4) included some of the most eminent professionals in Europe and the world. It was also attended by the IOMP President, Secretary General, Treasurer, Chair of ETC, Chair of AHC, IFMBE Secretary General, IUPESM Secretary General and EFOMP President-elect. The opinion of all the delegates at the conference was that the project will be an extremely useful tool for the profession.

EMITEL will be the first e-encyclopaedia of medical physics and is expected to be fully ready by the World Congress in Munich (September 2009), when it will be officially launched. Further, the results of this large and complex project will be published and EMITEL will continue to be supported and updated on the Internet.
The increase in the amount of medical equipment available for the treatment, diagnosis and monitoring of patients has placed a significant demand on in-house service teams for maintenance.

The Department of Medical Physics and Engineering in the Leeds Teaching Hospitals NHS Trust is responsible for the servicing and maintenance of medical equipment in this acute hospital, which is the largest teaching hospital in the UK and provides services for the local population and surrounding neighbourhood. In a month, nearly 3,000 items of medical equipment are serviced or repaired in the department. The different job types include acceptance of new equipment, planned preventative maintenance (PPM), planned performance checks (PPC) and repairs.

From figure 1, we can see that the acceptance testing jobs take on average less than an hour, whereas an average of almost two hours per job is spent on PPM and PPCs. Similarly the time spent on the planned activity is almost half that spent on repair work, a significant resource both in financial and human terms.

In some ways our current situation is analogous to a nurse vaccinating a large group of healthy patients while queues of sick patients wait to receive treatment for a serious disease. PPM work demands resources which result in other items of equipment remaining out of clinical service awaiting repair. This was the driver for our research on the possibility of increasing the existing service intervals, using risk assessment techniques.

National guidelines such as DB9801 (1998) and more recently DB2006 (05) recommend that equipment is serviced in accordance with the manufacturer’s instructions. Also, some inspections of medical equipment are now a legal requirement, e.g. for patient weighing scales. Current guidance from the MHRA states that: ‘The frequency and type of planned preventative maintenance should be specified, taking account of the manufacturer’s instructions, the expected usage and

---

Subashini Chandrasekaran and Giles Hartley (Leeds Teaching Hospitals NHS Trust) evaluate the risks involved in increasing service intervals on equipment.
the environment in which it is to be used.’

The recommendation is to take account of the manufacturer’s instructions and does not insist that we follow them explicitly.

There is scope for the application of informed judgement in Trust engineering departments on appropriate service intervals where there is no legislation in place that imposes an interval.

**RISK ASSESSMENT**

Risk assessment principles are commonly used in healthcare environments, and involve assigning a value to the likelihood of occurrence of a failure and the severity of that failure to derive a measure of risk. This may be on a scale of 1 to 5, for example where a score of 1 is given to ‘unlikely to occur’ or ‘no harm’ and a score of 5 is given to ‘almost certain to occur’ or ‘serious harm or death’.

Risk = likelihood × severity

A risk assessment model based on the papers reviewed in this article has already been used in Leeds Teaching Hospitals to determine which items of medical equipment should be included in a PPM programme or more importantly removed from the programme on the basis of acceptable risk. Increasing the service interval may allow us to release further resources for repairs without increasing risk. This resource can be used to improve repair turnaround times and ensure equipment is available to our patients when needed.

The aim of this project is to identify ways to increase available resources for repair work, by exploring the possibilities of extending the interval for planned maintenance jobs using risk assessment techniques. The approach is pursued by reviewing the models proposed in the literature and evaluating their suitability using data from the Trust’s equipment management database.

**METHODOLOGY**

We started by searching for articles in professional journals on planned maintenance of equipment. Standard library search engines were used with search criteria of articles in English on ‘planned maintenance’ and ‘reliability’. Articles were discounted which considered mechanical equipment where reliability is based on wear behaviour as this is not the case for the electro-medical equipment that is the subject of this article. Articles were also discounted which described models which required a large amount of numerical data and complex calculations such as Guida and Pulcini’s Bayesian analysis of repairable systems.

A patient ventilator (Puritan Bennett 840), volumetric infusion pumps (Graseby 500) and a patient monitor (Philips MP60) were selected from the Leeds equipment inventory as being in the high, medium and low risk categories, respectively.

In order to analyse the Leeds service history data for the three models it was necessary to define the term ‘failure’ because a request for repair may be due to a peripheral item such as a mains lead, external clamp or may even be due to user error. For this work we have defined equipment failure as a failure to perform its intended function. Repair jobs for physical damage or peripheral items such as cables and mains leads were excluded.

Three years’ worth of service data for these models of equipment (November 2005–October 2008) was extracted from the Leeds equipment management database for analysis. This involved reviewing almost 4,000 service reports and reclassifying the job types to extract the repairs that met our definition of failure.

The concept of observed mean time between failure and observed failure rate described by Smith, and Torell and Avelar was used to calculate values for the three equipment models selected using the following equations:

\[
\text{Failure rate} = \lambda = \frac{k}{t}
\]

Similarly, mean time between failure (MTBF) = θ

and the observed MTBF

\[
\theta = \frac{t}{k}
\]

where k = number of observed failures and t = total observed time.

**RESULTS**

**LITERATURE REVIEW**

Models by Fenningkoh and Smith, Capuano and Koritko, Ascota and Wang and Levenson were selected and reviewed. All of the selected studies were based on the work of Fenningkoh and Smith, and each of them evaluated their own risk, function and maintenance score for the equipment. A study by Cook was identified; however it had a different focus and therefore could not be used for the purpose of this study.

1. **FENNINGKOH AND SMITH**

Fenningkoh and Smith proposed a qualitative scoring system based on an assessment of the function of equipment, its clinical application, maintenance requirements and incident history. Each criterion was scored for each category of equipment to derive an equipment management (EM) number from the following equation:

\[
\text{EM} = \text{function} + \text{risk} + \text{required maintenance}
\]
The function score was assigned based on whether the equipment was used for diagnostic, therapeutic, analytic or other miscellaneous purposes. Therapeutic equipment was given the maximum score on the assumption that they provide some external energy to treat patients and hence possess the greater risk of injury to the patient.

The risk score considered the potential physical risk in terms of risk of harm to the patient or to the operator in the event of equipment failure. A score from 1 to 5 was used, ranging from no significant risk through to patient death.

Requirement for maintenance was not directly quantified, however the work considered the frequency of usage as the basis for maintenance and was scored from 1 for minimal maintenance required (e.g. laboratory water bath with only a visual inspection needed and a basic performance check) to 5 for items requiring extensive maintenance (e.g. ventilator with PM every 6 months).

Fenningkoh and Smith included equipment which had achieved an EM number above 12 in their proposed equipment maintenance programme.

2. ASCOTA
In 2000, Joseph Ascota proposed his model for clinical equipment management. According to him one important criterion of consideration for preventive maintenance (PM) was the equipment location (say in ICU, telemetry floor or emergency department). The equation proposed by Ascota added weightings to the basic Fenningkoh and Smith equation, according to how the author thought that function, equipment risk and maintenance requirements influenced equipment management. The equation for the EM number according to Ascota was as follows:

\[ EM = 0.5F + 0.25R + 0.25MR \]

where \( F \) = equipment function, \( R \) = risk and \( MR \) = maintenance requirement.

Another key difference between the Fenningkoh and Smith and the Ascota methods of evaluation is that Ascota introduces the maintenance requirements as a dynamic component (figure 2). It was calculated as the yearly average repairs per unit/per equipment type.

3. CAPUANO AND KORITKO
In 1996 Capuano and Koritko considered the same elements when designing a software database program called Risk Oriented Management System (ROMSYS), where they determined an algorithm for setting risk levels and automatic PM interval assignment. They also concentrated on highlighting the devices that required special attention. They framed the term ‘risk level’ (RL), which was a numeric value like the EM number, incorporating function (FR), consequence (CR – risk in the Fenningkoh and Smith model), protection (PR), lethality (LR), maintenance (MR) and use (UR). The maintenance category includes the need for any technical attention such as electronic adjustments, mechanical adjustments etc., and has a score of 50 for mandatory service. It is a cumulative scoring method that adds up according to the individual equipment’s maintenance needs. Protection considers the increase/decrease in the risk level of the equipment according to the provided protection factors like patient alarms, failsafe mechanisms etc. The lethality rating considers the presence of dangerous outputs from the device. Finally the score for use was considered to influence the potential failure of equipment and was rated from most frequently used to never used. The final formula being given by:

\[ RL = FR + CR + MR + PR + LR + UR \]

The risk level (RL) gives a maximum score of 99, and once it is determined the frequency of PM and service interval can be calculated as follows:

\[ PM \text{ frequency} = \frac{RL}{15} \]

and the interval = 1/(frequency/15)

The value 15 in the interval calculation is an adopted normalisation factor. Further, other criteria like time needed for completion of PM, risk level rating, test equipment requirements and battery check accounted for the remaining part of the scoring. That formed the CPF (comprehensive PM flag) scoring which was calculated as follows:

\[ CPF = TN + RL + TE + BC \]

where:
- \( TN \) is the time required to complete the PM (in minutes) or \( > 4 \) hours for a score between 0 and 6;
- \( RL \) is the assigned risk level depending on the score obtained for the above calculation, 0 to 99 score between 0 and 6;
- \( TE \) (test equipment) is based on the number of items of test equipment that would be required as an indication of the complexity of the work, score between 0 and 6;
- \( BC \) (battery check) is whether a battery check is required (score 6) to not required (score 0).

A total score of 10 or more indicates a need for off-site (workshop) planned maintenance.

4. WANG AND LEVENSON
In 2000 Wang and Levenson proposed their model for their equipment management where they modified the ‘Function’ component of the basic Fenningkoh and Smith equation to include ‘mission criticality’ to obtain an equipment management rating (EMR). They considered the criticality of the function of a particular piece of equipment in relation to the overall mission of the organisation and not the individual clinical department. They proposed an equation for calculating the EMR as follows:
In this model risk scores were taken from the ECRI (1995) list in which the high risk devices were given a score of 5, the medium risk devices a figure of 3 and the low risk devices were assigned a value of 1. The maintenance requirements were adopted from the Fenningkoh and Smith model. The multiplication factor of 2 was used in order to provide equal weight to all three of the parameters. However the number of units of each device type was not considered. Also, in order to achieve accuracy in the calculation, Capuano and Koritko included a value for utilisation in the adjusted EMR calculation as in the following equation:

$$AEMR = (mission\ critical + 2\times maintenance) \times utilisation + 2\times risk$$

In 2001 ECRI revised their method of risk classification and released an Inspection and Preventive Maintenance computer program (IPM) for planned maintenance and inspection schedules. The ECRI software database can be used to calculate the EM score which will in turn determine the PM intervals. They classified the equipment risk as shown in table 1 and provide a detailed list of equipment categories under each classification.

### TABLE 1

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High risk devices</td>
<td>Life support, key resuscitation, critical monitoring, energy emitting and other devices whose failure or misuse leads to serious patient/staff injury</td>
</tr>
<tr>
<td>Medium risk devices</td>
<td>Diagnostic instruments whose misuse, failure or absence (e.g. out of service with no replacement available) would have serious patient impact, but no direct serious injury</td>
</tr>
<tr>
<td>Low risk devices</td>
<td>Devices whose failure or misuse is unlikely to result in any serious consequences</td>
</tr>
</tbody>
</table>

### TABLE 2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EM score</td>
<td>EM score</td>
<td>EM score</td>
<td>EM</td>
<td>AEMR</td>
</tr>
<tr>
<td>Ventilator</td>
<td>20</td>
<td>17</td>
<td>41</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td>Infusion pump</td>
<td>14</td>
<td>13</td>
<td>12/11</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Monitor</td>
<td>13</td>
<td>11</td>
<td>19</td>
<td>23</td>
<td>19</td>
</tr>
</tbody>
</table>

### TABLE 3

<table>
<thead>
<tr>
<th>Item</th>
<th>Cumulative observation time (days)</th>
<th>Number of failures observed $k$</th>
<th>MTBF (days) $t/k$</th>
<th>Failure rate (%) $k/t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilator</td>
<td>64,418</td>
<td>264</td>
<td>244.01</td>
<td>0.41</td>
</tr>
<tr>
<td>Infusion pump</td>
<td>852,176</td>
<td>521</td>
<td>1,635.7</td>
<td>0.061</td>
</tr>
<tr>
<td>Patient monitor</td>
<td>120,578</td>
<td>7</td>
<td>17,225.36</td>
<td>0.0058</td>
</tr>
</tbody>
</table>
There are a relatively high maintenance requirements for the function classification of the equipment. The time spent by the technicians to rectify each of the faults of the equipment and to be able to differentiate between different types of faults reported on equipment is high. This may be explained by the fact that the ECRI 1995 classification did not consider energy emitting devices but the 2001 version did include energy emitting devices in the high risk device list. However we do not think this explains why the infusion pump classification changed from medium risk to high risk with the above addition.

From table 1 we can also see that although Fennigkoh and Smith’s work formed the base for all the EM scoring, there were still differences in the scoring between each author. This may be explained as follows:

- the level of risk considered varies: subjective judgement;
- the function classification of the equipment varies from hospital to hospital;
- the maintenance requirements differ between various models and manufacturers.

Above all, the perception of the importance of equipment varies between persons. This may also be due to some equipment such as ventilators falling into both ‘life saving’ and ‘life supporting’ categories. This serves to highlight the subjective nature of such qualitative judgements.

One other interesting comparison between Fennigkoh and Smith and ECRI in classifying the equipment risk is that the former classified monitors to be a lower risk than infusions pumps while the latter classifies monitors as high risk equipment.

**LEEDS HOSPITAL DATA**

Our research included analysis of data from the Leeds Teaching Hospitals database. As a first step towards this, we had reviewed the data and made the following observations:

- There is variability of the frequency of faults recorded on equipment each year which suggests a random failure rate.
- There is misclassification of the equipment faults in the database. There is a need to better differentiate between different types of faults reported on equipment and to be able to review the most frequent and recurring faults to meet our definition of failure.
- There are a relatively high number of reported cases of physical damage to the equipment caused by the mishandling.
- The time spent by the technicians to rectify each of the faults of the equipment including the preventive maintenance is adequately recorded.
MTBF calculations based on equipment history data tend to produce a high value because they are based on the failure rate of a device as measured during its useful life. For the purposes of this calculation we have to assume that this will continue indefinitely. Mechanical effects such as wear out would tend to limit the equipment life earlier than an MTBF calculation would predict.

For example, if we take 100,000 25-year-olds in a sample of the population and during one year 125 die (a failure) then we have:

\[ 100,000 \times \frac{1}{25} = 100,000 \text{ man years} \]

The failure rate is thus 125/100,000 = 0.125 per cent per year.

As MTBF is the inverse of failure rate:

\[ \text{MTBF} = \frac{1}{0.00125} = 800 \text{ years!} \]

Clearly 800 years is unrealistic for any human, however it does suggest that reliability is good in the short to medium term. If this is applied to medical equipment then it could be used to predict the failure rate in the short to medium term. This also highlights the need to understand failure patterns for medical equipment. Most engineers will recognise the bathtub curve as an equipment reliability plot that describes high infant mortality, a period of constant (random) failure rate and a wear out zone. However this model may not be true for some or all medical equipment.

**CONCLUSION**

We conclude that each of the models that have been identified has limitations which reduce its potential for acting as a basis for extending the interval for planned maintenance jobs in a medical equipment management service. Any adopted model should utilise a combination of risk assessment and quantitative data.

Reviewing the data in tables 2 and 3, it is clear that only Ascota’s model shows some correlation with our data. Taking MTBF as an indicator of service interval illustrates that our ventilators are likely to fail after 244 days of use where as a patient monitor has a MTBF of 17,225 days. As ventilators are currently serviced at 6 month intervals this could be seen as an indicator that the current interval is correct, however we do not believe that this is a measure of the effectiveness of the planned maintenance work. Equally when applying the ECRI or Fennigkoh’s risk assessment scores it was judged that ventilators were ‘high risk’, as part of the assessment concluded that failure could result in patient death. Over the 3 year study period 264 failures (excluding peripheral items) have been recorded with no incidence of patient death or harm.

This leads us to question if we are considering risk in the correct context. Wang and Levenson suggest considering risk in an organisational context which may be more appropriate.

A dynamic component is necessary to indicate a change in reliability of failure rate as we are making the assumption that failure rate is constant, i.e. random over the life of the equipment. If the service interval was too great we would expect reliability to fall. It would be an advantage to be able to modify the service interval in response to this change in order to manage the associated risk. Clearly the ideal dynamic component would give a quantitative measure of the effectiveness of planned maintenance and filter out genuine random failures.

**FURTHER WORK**

Designing appropriate data input criteria for the equipment database will be an essential next step if data analysis is to be performed. We propose the use of a simple risk assessment model initially based on the work of Ascota, moving to more comprehensive modelling when improved data collection allows. We believe that for a model to work it must be relatively simple and include a feedback mechanism which makes use of local data (as in figure 2).

It would be an advantage to be able to modify the service interval in response to this change in order to manage the risk.

**REFERENCES**

CORRELATION COEFFICIENT: ASSOCIATION BETWEEN TWO CONTINUOUS VARIABLES

Dr Jenny Freeman and Dr Tracey Young use statistics to calculate the correlation coefficient: the association between two continuous variables.

Many statistical analyses can be undertaken to examine the relationship between two continuous variables within a group of subjects. Two of the main purposes of such analyses are:

- To assess whether the two variables are associated. There is no distinction between the two variables and no causation is implied, simply association.
- To enable the value of one variable to be predicted from any known value of the other variable. One variable is regarded as a response to the other predictor (explanatory) variable and the value of the predictor variable is used to predict what the response would be.

For the first of these, the statistical method for assessing the association between two continuous variables is known as correlation, whilst the technique for the second, prediction of one continuous variable from another, is known as regression. Correlation and regression are often presented together and it is easy to get the impression that they are inseparable. In fact, they have distinct purposes and it is relatively rare that one is genuinely interested in performing both analyses on the same set of data. However, when preparing to analyse data using either technique it is always important to construct a scatter plot of the values of the two variables against each other. By drawing a scatter plot it is possible to see whether or not there is any visual evidence of a straight line or linear association between the two variables.

This tutorial will deal with correlation, and regression will be the subject of a later tutorial.

CORRELATION

The correlation coefficient is a measure of the degree of linear association between two continuous variables, i.e. when plotted together, how close to a straight line is the scatter of points. No assumptions are made about whether the relationship between the two variables is causal, i.e. whether one variable is influencing the value of the other variable; correlation simply measures the degree to which the two vary together. A positive correlation indicates that as the values of one variable increase the values of the other variable increase, whereas a negative correlation indicates that as the values of one variable increase the values of the other variable decrease. The standard method (often ascribed to Pearson) leads to a statistic called $r$, Pearson’s correlation coefficient. In essence $r$ is a measure of the scatter of the points around an underlying linear trend: the closer the spread of points to a straight line the higher the value of the correlation coefficient; the greater the spread of points the smaller the correlation coefficient. Given a set of $n$ pairs of observations $(x_1, y_1), (x_2, y_2), ..., (x_n, y_n)$ the formula for the Pearson correlation coefficient $r$ is given by:

$$
r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}$$

Certain assumptions need to be met for a correlation coefficient to be valid as outlined in Box 1. Both $x$ and $y$ must be continuous random variables (and Normally distributed if the hypothesis test is to be valid).

Pearson’s correlation coefficient $r$ can only take values between $-1$ and $+1$; a value of $+1$ indicates perfect positive association (figure 1), a value of $-1$ indicates perfect negative association (figure 2), and a value of $0$ indicates no linear association (figure 3).

The easiest way to check whether it is valid to calculate a correlation coefficient is to examine the scatterplot of the data. This plot should be produced as a matter of routine when correlation coefficients are calculated, as it will give a good indication of whether the relationship between the two variables is roughly linear and thus whether it is appropriate to calculate a correlation coefficient all. In addition, as the

**FIGURE 1.** Perfect positive correlation ($r = +1$).

**FIGURE 2.** Perfect negative correlation ($r = -1$).

**FIGURE 3.** No linear association ($r = 0$).

**FIGURE 4.** The correlation for this plot is 0.8. It is heavily influenced by the extreme cluster of four points away from the main body.
The correlation coefficient is highly sensitive to a few abnormal values, a scatterplot will show whether this is the case, as illustrated in figures 4 and 5.

**EXAMPLE**
Consider the heights and weights of 10 elderly men:

(173, 65), (165, 57), (173, 77), (183, 89),
(178, 93), (188, 73), (180, 83), (183, 86),
(163, 70), (178, 83)

Plotting these data indicates that, unsurprisingly, there is a positive linear relationship between height and weight (figure 6). The shorter a person is the lower their weight and, conversely, the taller a person is the greater their weight. In order to examine whether there is an association between these two variables, the correlation coefficient can be calculated (table 1). In calculating the correlation coefficient, no assumptions are made about whether the relationship is causal, i.e. whether one variable is influencing the value of the other variable.

Thus the Pearson correlation coefficient for these data is 0.63, indicating a positive association between height and weight. When calculating the correlation coefficient it is assumed that at least one of the variables is Normally distributed. If the data do not have a Normal distribution, a non-parametric correlation coefficient, Spearman’s rho ($r_s$), can be calculated. This is calculated in the same way as the Pearson correlation coefficient, except that the data are ordered by size and given ranks (from 1 to $n$, where $n$ is the total sample size) and the correlation is calculated using the ranks rather than the actual values. For the data above the Spearman correlation coefficient is 0.59 (table 2).

The square of the correlation coefficient gives the proportion of the variance of one variable explained by the other. For the example above, the square of the correlation coefficient is 0.398, indicating that about 39.8 per cent of the variance of one variable is explained by the other.

**HYPOTHESIS TESTING**
The null hypothesis is that the correlation coefficient is zero. However, its significance level is influenced by the number of observations and so it is worth being cautious when comparing correlations based on different sized samples. Even a very small correlation can be statistically significant if the number of observations is large. For example, with 10 observations a correlation of 0.63 is significant at the 5 per cent level, whereas with 150 observations a correlation of 0.16 is significant at the 5 per cent level. Figure 7 illustrates this.

The statistical test is based on the test statistic $t = r \sqrt{n-2}/\sqrt{1-r^2}$ which under the null hypothesis follows a Students’ $t$ distribution on $n-2$ degrees of freedom and the confidence interval is given by:

The standard error of $r = \frac{1-r^2}{\sqrt{n-2}}$

For the Pearson correlation coefficient above the standard error is 0.27, the $t$ statistic is 2.30 and the $P$-value is 0.05.

**WHEN NOT TO USE A CORRELATION COEFFICIENT**
Whilst the correlation coefficient is a useful measure for summarising how two continuous variable are related, there are certain situations when it should not be calculated, as has already been alluded to above. As it measures the linear association between two variables, it should not be used when the relationship is non-linear. Where outliers are present in the data, care should be taken when interpreting its value. It should not be used when the values of one of the variables are fixed in advance, for example when measuring the responses to different doses of a drug. Causation should not be inferred from a correlation coefficient. There are many other criteria that need to be satisfied before causation can be concluded. Finally, just because two variables are correlated at a particular range of values, it should not be assumed that the same relationship holds for a different range.

**SUMMARY**
This tutorial has outlined how to construct the correlation coefficient between two continuous variables. However, correlation simply quantifies the degree of linear association (or not) between two variables. It is often more useful to describe the relationship between the two variables, or even predict a value of one variable for a given value of the other and this is done using regression. If it is sensible to assume that one variable may be causing a response in the other then regression analysis should be used. If, on the other hand, there is doubt as to which variable is the causal one, it would be most sensible to use correlation to describe the relationship. Regression analysis will be covered in a subsequent tutorial.
### TABLE 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>$x$</th>
<th>$x - \overline{x}$</th>
<th>$(x - \overline{x})^2$</th>
<th>$y$</th>
<th>$y - \overline{y}$</th>
<th>$(y - \overline{y})^2$</th>
<th>$(x - \overline{x})(y - \overline{y})$</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>173</td>
<td>-3.5</td>
<td>12.25</td>
<td>65</td>
<td>-12.5</td>
<td>156.25</td>
<td>43.75</td>
</tr>
<tr>
<td>2</td>
<td>165</td>
<td>-11.5</td>
<td>132.25</td>
<td>57</td>
<td>-20.5</td>
<td>420.25</td>
<td>235.75</td>
</tr>
<tr>
<td>3</td>
<td>174</td>
<td>-2.5</td>
<td>6.25</td>
<td>77</td>
<td>-0.5</td>
<td>0.25</td>
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</tr>
<tr>
<td>4</td>
<td>183</td>
<td>6.5</td>
<td>42.25</td>
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<td>11.5</td>
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<td>74.75</td>
</tr>
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<td>5</td>
<td>178</td>
<td>1.5</td>
<td>2.25</td>
<td>93</td>
<td>15.5</td>
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**TABLE 1.** Calculation of Pearson’s correlation coefficient ($r$).

$x = 1765 / 10 = 176.5$ cm  \( \overline{y} = 775 / 10 = 77.5 \) kg  \( r = 505.50 / \sqrt{(558.50*1148.50)} = 0.63 \)

### TABLE 2

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<th>Rank ($y$)</th>
<th>$y - \overline{y}$</th>
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**TABLE 2.** Calculation of Spearman’s rank correlation coefficient ($r_s$).

$x = (ranks) = 55 / 10 = 5.5 \overline{y} = (ranks) = 55 / 10 = 5.5 \quad r_s = 48.5 / \sqrt{(82.5*82.5)} = 0.59$

### BOX 1: The assumptions underlying the validity of the hypothesis test associated with the correlation coefficient

1. The two variables are observed on a random sample of individuals.
2. The data for at least one of the variables should have a Normal distribution in the population.
3. For the calculation of a valid confidence interval for the correlation coefficient both variables should have a Normal distribution.
IN FEBRUARY, I ATTENDED the International Conference on Aging, Disability and Independence (www.icadi.phhp.ufl.edu/) in St Petersburg, Florida. IPEM funded a substantial proportion of my costs for the conference under the travel bursary scheme. St Petersburg, known locally as St Pete, is a city built on a peninsula between Tampa Bay and the Gulf of Mexico. It has a warm sunny climate, a pier and plenty of fresh and tasty seafood.

The conference was multi-track, covering:

- Assistive technology: papers on outcome measures, and assistive technology development and evaluation.
- Cross-cutting issues: papers on topics that bridge multiple disciplines.
- Injury prevention: this track addressed falls, fire safety, poisons, pedestrian safety and other issues related to ensuring a safe environment within the home and community.
- Liveable homes and communities: this track examined strategies to support personal independence as people age in the built environment, focusing on universal design, housing, and community infrastructure. Session topics included research, methods to measure effectiveness, tools for design, best practices and policy analysis.
- Smart homes/robotics: this track linked two themes, covering the design and evaluation of smart homes for people with many different disabilities and the design and evaluation of assistive robotic systems.
- Telehealth: obtaining the physical presence of a doctor where needed is often not possible. Telehealth systems use communications technology to link people and health and physiological measurement equipment with their doctor at a remote location.
- Transportation: this became a substantial theme of the conference. There was much discussion of the provision and accessibility of public transport for able and disabled people, as well as the development of accessible transportation systems. This track had more of an American focus than some of the other tracks due to the minimal public transport services available there outside of most major urban centres.
- Work and aging: as the population ages, people will need to be able to work for longer. This track examined issues around the aging working population, and how people can be enabled to continue to work for longer. I attended a pre-conference workshop on outcome measures, and then the assistive technology and smart homes/robotics tracks.

**OUTCOME MEASURES WORKSHOP**

The workshop was led by a team from the Consortium for Assistive Technology Outcomes Research (CATOR, www.atoutcomes.com). They presented outcome measures that they have developed such as the Psychosocial Impact of Assistive Devices Scale (PIADS) and Quebec User Evaluation of Satisfaction with assistive Technology (QUEST). Discussion was mainly around the use of outcome measures in more difficult contexts, such as using them over long-term periods or with cognitively disabled groups. The workshop also addressed issues around measuring the impact of carers as well as disabled people.

**ASSISTIVE TECHNOLOGY TRACK**

Much of the assistive technology track was focused on the development of new outcome measures and the application of existing measures for assessing the impact of rehabilitation and assistive technology interventions. My own interest in this area was to find outcome measures that could be used to measure the impact of assistive technology on people with dementia. One of the presentations was about technology-assisted outcome measures where technology has been applied to the filling-in of forms and answering questionnaires. A company (www.mi-corporation.com) has converted PIADS for use with a digital pen. The pen tracks its position on the page using a faint pattern of dots. As the form is filled in, data is stored in the pen for subsequent download to a computer. No screens or tablet PCs are necessary at the point of collection of the data.

**SMART HOMES/ROBOTICS TRACK**

There was a diverse range of work presented at the smart homes/robotics track ranging from smart house systems for people with dementia to mobile anthropomorphic assistive robots that respond to speech commands. Suzanne Martin (University of Ulster, Northern Ireland) reported on the European COGKNOW project (www.cogknow.eu) which is ‘helping people with mild dementia to navigate their day’, and also on the TRAIL (Technologies for Rurality, Ageing and Independent Living Labs project (openlivinglabs.eu)).

COGKNOW is a large European collaboration that is developing mobile assistive devices for people with mild cognitive impairment or early stage dementia. The devices are designed to help people to remember, maintain social contact, perform daily life activities and enhance their feelings of safety.

The paper I presented at this session described our work developing and evaluating smart house systems for people with dementia, in particular a 1-year evaluation of a smart flat for a man with dementia in Deptford. The autonomous technology clearly benefited him, reducing his incontinence, night-time wandering and substantially increasing his sleep. His daughter was also pleased with the technology, reporting that it reduced her anxiety about his safety and well-being. The abstract and slides from the presentation can be supplied on request by emailing t.d.adlam@bath.ac.uk.
The most interesting robotics paper presented was from a group in Korea led by Zenn Bien (Korea Advanced Institute of Science and Technology). They have been developing mobile assistive robots for the domestic environment. They presented two papers, one being of a gantry-based robot that could respond to voice commands and support a person confined to bed. It could assist with tasks such as making a hot drink or feeding. The other robot was a mobile device that also responded to voice commands. The group has been developing a complex intelligent user interface that associates tasks, actions and verbal instructions. The robot provides cognitive support and is able to assist with reminders and task sequencing.

ICADI is an excellent multidisciplinary conference with delegates from all over the world covering a broad range of topics. It is well attended and the presentations were in general of a high quality. I recommend it to people working in the fields of disability or aging, but also to engineers looking for clinical context for their work. The conference is positioned at the interface of engineering and the professions allied to medicine. The next ICADI will be in 2010.

**TRANSATLANTIC WORKSHOP**

I returned to the UK via Toronto and met a researcher from the University of Toronto who is also working on assistive technology for people with dementia. Over a pint in what was an English country pub translated to Toronto, we discussed plans for a forthcoming workshop in our field before I returned to my hotel for an early morning flight back to the UK. That workshop has now been cofunded by EPSRC (Engineering and Physical Sciences Research Council) and the Canadian Institutes of Health Research Institute of Aging, and has had the first of two meetings in Toronto. The return meeting will be held in Bath in March 2009.

This report might have been longer, but unfortunately my extensive notes taken during the sessions were stolen along with my laptop when I moved house after arriving back in the UK.
the donation of the current building where the institute is located. This was to provide help for children with disabilities. At the beginning there were only five children with various disabilities and six members of staff.

Even now there are not many specialist centres that offer services to physically disabled children in Mexico. Some NAI clients have to travel for hours to use the services available at NAI.

Thirty years on, the institute has 280 children on its list of patients and 130 members of staff. The institute is not residential but provides schooling for children with disabilities along with medical and therapy care.

The centre continues to be funded through charitable donations and is also supported by a UK-based charity called MeDiCT (www.medict.co.uk). Their support provides expert training for the therapists and provision of special wheelchairs and equipment for the children with disabilities.

For years CHCS has had links with the institute and provided the staff with help and support in postural management. While Terry and I were in Mexico, we also ran a 1-day clinic and saw a few children with complex physical disabilities. The clinic was organised to look at some issues surrounding postural management and power mobility.

CONFERENCE
The conference took place at the Cintermex in Monterrey, which is the capital city of the northeastern Mexican state of Nuevo León. The city is also known as ‘Sultana del Norte’ (Northern Sultan). It is named after the Countess of Monterrei (a city in Galicia, Spain), wife of the Viceroy of New Spain, Gaspar de Zúñiga y Acevedo, Count of Monterrey.

The venue (Cintermex) is located on what used to be the Monterrey Foundry which closed in the 1980s. As you walk in the park outside the building you can still see the equipment that was used in the Foundry (figures 1 and 2).

The sponsors were the State Government of Nuevo León, Department of Family Integration, Health Services and Commissionaires for People with Disability of the State of Nuevo León and Social Services.

The chairman of the opening ceremony was Juan Carlos Tolentino who was one of the managers of Social Services Organisation in the state of NL. He introduced the keynote speaker Jesus Cornado (President, Commission for People with Disability). Mr Cornado was also the person who initially approached the governor of the state of NL to join him in organising the multi-disciplinary conference.

Aimo Stromberg (Secretary General, International Cerebral Palsy Society, ICPS, Finland) was amongst the speakers who drew the delegates’ attention to the activities of the ICPS. He talked about ICPS’s involvement in different countries. The ICPS has organised more than 80 seminars in over 35 countries. They have sent practitioners to developing countries to provide help appropriate to their needs.

Also amongst the speakers were disabled people and parents of children with disabilities, who talked about their own experiences.

I think the conference met the objectives of its initial set-up and provided the delegates with a good overview of the different types of physical and cognitive disabilities in children and adults. It covered a wide range of issues concerned with those disabilities including views of those living with disabilities. It also provided great networking opportunities for professionals in and out of Mexico.
RADIOGRAPHER QUALITY ASSURANCE TRAINING DAY

ANITA JEFFERIES  Secretary DRSIG, City Hospital, Birmingham

MANCHESTER DENTAL EDUCATION CENTRE (MANDEC)  12th November 2008

THIS WAS THE SECOND outing for this course, organised by the Diagnostic Radiology SIG. Talks were based on the ‘level A’ tests in IPEM91, and the target audience was radiographers who are involved in their department’s QA programme.

Eighty per cent of the delegates were radiographers, most of the rest were clinical technologists plus a few physicists. There were stands exhibiting QA equipment from Imaging Equipment, Northern Physics Services, Qados and Southern Scientific, which had a lot of visitors during the lunch and coffee breaks.

The teaching was provided by generous volunteers, physicists and radiographers from the world of diagnostic radiology. The day was divided into four sessions.

MORNING SESSIONS

In session 1, we had an overview of QA programmes in general, starting with a talk from Peter Hiles (Glan Clywd Hospital, Rhyl) outlining the legislation that requires QA to be performed and the guidance available on how to actually do the tests. This was followed by a description of a very thorough and successful QA programme by Stewart Whitley (independent Radiology Advisor, formerly of Blackpool Hospital).

Session 2 got us into the practicalities of how to actually perform the tests. Navneet Dulai (King’s College London) started off the session with tests of the tube, generator and automatic exposure controls. In a change to the advertised programme, Navneet was followed by David Brettle (Leeds General Infirmary) who reminded us that display monitors are an important (and often overlooked) part of the imaging chain and described some methods of setting up and testing them. Finally, David Platten (Northampton General Hospital) took us through the QA tests to be performed on CT scanners.

AFTERNOON SESSIONS

After lunch and some very nice desserts (and fruit salad for the healthy), Chris Wood (Northampton General Hospital) talked about the QA of digital systems – CR readers and DR detectors. While this subject still feels new to a lot of users, most centres now have at least some digital equipment, which needs to be included in the quality assurance programme. Chris was followed by Claire Skinner (Royal Free Hospital, London) who told us how to perform quality assurance on fluoroscopy systems without losing the will to live (even physicists get bored of counting dots on test objects), and Donald Emerton (KCARE, London) who managed to persuade us that reject analysis is worthwhile.

In session 4 Sharan Packer (Bradford Royal Infirmary) explained the ‘what, when and who’ of incident reporting, followed by Matt Dunn (Nottingham University Hospital) who gave us an overview of patient dose audits and diagnostic reference levels – another subject that is often overlooked in QA programmes.

The meeting finished with a lively discussion period. It seems, not surprisingly, that digital systems are currently the biggest challenge to QA radiographers. This was reflected in the course feedback – Chris’s talk on CR and DR QA came out top in the question: ‘Which presentation did you find most useful?’ Overall the feedback was very positive, with a few pointers on how to improve the meeting for next time.

2ND NEUROPHYSIOLOGICAL INTRA-OPERATIVE MONITORING

ROSIE STEELE  Oxford Radcliffe Hospitals Trust

IPEM, YORK  6th November 2008

THIS MEETING, ORGANISED BY the Physiological Measurement Special Interest Group, was held at IPEM headquarters. It was heartening to see over 40 delegates attend the day, as neurophysiological intra-operative monitoring (IOM) is a specialised area of work performed by a small band of dedicated professionals. The Scientific Organiser, Rosie Steele (Oxford Radcliffe Hospitals Trust) opened the meeting by welcoming the delegates, speakers and sponsors (Kallista Medical, Optima Medical and Seren Medical). We were fortunate to have well-respected experts in their field conveying their knowledge in an interesting and informative manner. To ensure topics were thoroughly covered the day was limited to seven talks ranging from half an hour to an hour.

The first speaker of the day, Karen Holmes (Royal National Orthopaedic Hospital, Stanmore) reminded us of ultimately why we perform intra-operative monitoring and the traces we are likely to come across with the various methods of monitoring (figure 1). She then went on to present an audit run at Stanmore that demonstrated what the surgeon considered to be a significant SEP (somatosensory evoked potential) trace change (figure 2).
FIGURE 1. Traces from various methods of monitoring.

FIGURE 2. Somatosensory evoked potential trace change.

What do you consider constitutes a significant change in SEP traces?

- decrease in amplitude $\geq 25\%$ from baseline which is consistent ✓
- decrease in amplitude $\geq 50\%$ from baseline which is consistent ✓ ✓ ✓ ✓ ✓
- decrease in amplitude $\geq 60\%$ from baseline which is consistent ✓ ✓ ✓ ✓
- an increase in latency ✓ ✓ ✓
- change in waveform morphology ✓ ✓
FIGURE 3. Theory of electrode placement and the terminology.

FIGURE 4. Recording set-up at Royal National Orthopaedic Hospital, Stanmore.
FIGURE 5. The brachial plexus surgical site.

FIGURE 6. Positioning of the motor evoked potential stimulating electrodes.
and what they were then likely to do once they were informed of a detrimental event. Five case studies then followed. Each consisted of the patient history, monitoring traces up to the event and the options available to the surgeon. We then heard what the surgeon actually did, the outcome from that decision and what the monitoring team could learn from this.

David Andrews (Oxford Radcliffe Hospitals Trust) then spoke on motor monitoring. This is an up-and-coming area that surgeons are requesting at a rapid rate. The talk was an amalgamation of journal reviews, feedback from a course run in Switzerland and observation from visiting other centres that perform motor evoked potentials (MEP). For example, the theory of electrode placement and the terminology used within the profession was described, with the aid of figure 3. The talk was well received and produced many questions and an extensive discussion to conclude.

Gemma Cannon (Royal National Orthopaedic Hospital, Stanmore) took us away from the spinal cord and into the realms of peripheral nerves, specifically the work she does with monitoring the lesions of the brachial plexus. Figure 4 shows the recording set-up used at Stanmore and figure 5 shows the surgical site.

MULTIMODAL MONITORING

We reconvened after a break to listen to Michael Glasby (Royal Hospital for Sick Children, Edinburgh) guide us through the practical details of multimodal monitoring, as used in Edinburgh. Figure 6 shows the positioning of the MEP stimulating electrodes, figure 7 the positioning of the recording electrodes and figure 8 the monitoring system.

We were asked the question ‘H-reflex – does it have a role in monitoring?’ by Christine Reber (Royal Surrey County Hospital, Guilford). Thankfully her slides lead us through the process: what is an H-reflex, the procedure to record a trace, clinical relevance and purpose of monitoring. We were also cautioned on associated physiological and technical problems, i.e. compartment syndrome and inadequate placement of subdermal needles.

Jim Oluwole (University Hospital of North Staffordshire, Stoke-on-Trent) was in the privileged position of having worked in two clinical neurophysiology departments and so began with giving the attendees a light-hearted comparison between the two working practices. He then went on to present an interesting case which identifies a lack of communication or follow-up that sometimes arises after adverse events. Our involvement as a monitoring service usually stops once the patient leaves the theatre; very rarely do we hear the final outcome of the patient. Jim left us with a number of questions that could be incorporated into a UK survey of practice.

It was the task for Christine Reber to conclude with a short presentation followed by an American video on direct nerve stimulation and pedicle screw monitoring. In the final discussion of the day the spinal cord monitoring web-based forum was promoted as an excellent tool for keeping professionals in this field in touch with each other and any new techniques. Anyone wishing to join SCM-UK should contact helen.grover@nnuh.nhs.uk.

It only leaves me to thank the speakers for imparting their knowledge and Alice Fields from IPEM for her great support throughout the whole organisation of this meeting. ■

![FIGURE 7. Positioning of the motor evoked potential recording electrodes.](image-url)
Stephen Roper (Warwick Business School, Coventry) set the scene with a description of innovation according to William J. Baumol of Princeton University as ‘a ferocious arms race among firms in the most rapidly evolving sectors of the economy’. Within organisations there has now emerged a new organisational competency to manage the innovation process effectively. Also, the trend is now for ‘open’ innovation – where ideas and concepts can be exported/imported on a more flexible basis within/across an organisation – rather than work only with ‘home grown’ intellectual property. This also identifies a culture of ‘passing on’ innovative concepts which an organisation does not have the expertise or the resources to exploit appropriately.

David Gleaves (MidTech – NHS Innovations West Midlands, Birmingham) outlined the role of the nine NHS National Innovation Centres in England and the corresponding organisations in Scotland, Wales and Northern Ireland. It was pointed out, however, that innovation in the NHS is now more widely interpreted and the general improvement of patient care, income generation or cost savings and improvement of internal culture and staff retention is as ‘relevant’ as marketable inventions. If medical physics departments are not in useful dialogue with their local ‘hubs’ then it is probably time that they should be. They would probably be pleasantly surprised if they entered their current development projects into the ‘hub’ annual innovation competitions. A feature of innovation hubs is also now to facilitate ‘problem and solution’ forums where problems in healthcare are identified, available solutions noted and remaining problems fed forward to relevant agencies. A key role of such hubs at the early stages of projects is to protect intellectual property.
Chris Johnson (Coventry School of Art and Design) outlined basic elements of ‘good design’ with specific reference to medical products. As he said, ‘design is everywhere’. (Check out Golden Section geometry within iPod products.) It was noted that elements of design now have to deal with issues of sustainability in order to meet customer expectations – although with regard to medical equipment, this is currently not yet a major product focus. Looking somewhat far ahead to ‘nanobots’, he identified that whole new concepts of design and control will be required to be used with such micro machines.

**KNOWLEDGE TRANSFER PARTNERSHIPS**

Mike Pelling (University of Coventry) outlined elements of Knowledge Transfer Partnerships (KTPs) where graduate placements within companies (or hospitals) under academic supervision can be used to develop innovative products/services. With up to 60 per cent of funding available of total annual costs of £40,000, the KTP process plays on the strengths of transfer of technology and knowledge within an industrial framework, development/employment opportunities for graduates and collaboration between industry and academia. This KTP process identifies an ‘innovation triangle’ where the academic component provides the component of administration and project management, the NHS partner provides the original idea and framework for innovation development and the industrial partner aspects of commercial development of the innovation.

Elizabeth Dymond (North Bristol NHS Trust) outlined her role in managing innovation within the NHS. This highly-relevant presentation described the role of providing a focus for ‘innovation’ within a large acute Trust where the ‘R&D’ department is due to become the ‘Research & Innovation Unit’. Specific reference was made to the role of Biomed Health Technology Co-operative (www.biomedhtc.org.uk) and also to the Lord Darzi report (High Quality Care For All). The audience was impressed by the scope and professionalism of the approach to innovation management at local level, where a critical factor is the ability to interact effectively with local teams. It was also identified that the development of innovation within an NHS Trust is ‘good news’ and regarded as a positive factor for staff morale and the general reputation of a Trust.

An opportunity was provided in the lunchtime break to visit the Design Hub within the TechnoCentre complex (figures 1 and 2), where student design projects and a rapid prototyping system were open to inspection. This component had been organised by Simon Fielden of the Health Design and Technology Institute, which is due to open in 2009.

**BRITISH STANDARDS**

James Love (Innoventions International Ltd, Miami, USA) provided a ‘route map’ of CE marking of medical devices. A key element of his presentation was to emphasise that maximum effort was required in the early stages of product development, i.e. knowledge acquisition, concept design and design detail, rather than the subsequent stages of prototype building, pilot production and production ramp up. It is no surprise that project development techniques in Japan will tend to place maximum effort in its initial stages, while in the west it tends to be a process of catch-up of design during the final stages of gearing up for manufacture (have you seen *The Apprentice*?). He spoke in detail on the implementation of appropriate risk management standard EN ISO 14971:2007 and described applicable risk tools such as SWIFT, HAZOP, FMCA, HEA, SHERPA and FMEA. The role of BS EN ISO 13485:2003 was referenced as the identified standard for development of medical devices.

Steven Crook (Salisbury District Hospital) described his experience of implementing ISO13485:2003 as a key component of implementing CE marking of medical devices within Odstock Medical. This process reflected the requirement to implement a quality system that would allow developed and manufactured products such as the Odstock Dropped Foot Stimulator to be CE marked within the Medical Device Directive. Key aspects of the design process were identified in order to meet the requirement that ‘the organisation has to ensure a planned and systematic approach to the control of product design and development’.

**RAPID PROTOTYPING SYSTEMS**

David Price (Laser Lines Ltd, Banbury) described the capabilities of the Stratasys range of rapid prototyping (RP) systems used extensively to shorten development cycles and now also for limited batch manufacture. The heart of each RP system is a fixed dual deposition head where heated model material or support material is...
FIGURE 3. Redesign of counter torque instrument for fastening screws into a vertebrae implant (courtesy Laser Lines Ltd).

FIGURE 4. Schematic of 'model' material head and 'support head' of rapid prototyping system. The heads are essentially static while the material is built up below on a moveable table.
extruded to either build the model or support its construction. Engineering grade thermoplastics available include ABS, ABSi, ABS M30, polycarbonate (various) and PPSF. Support material can be readily removed from the design build after manufacture. The use of RP technology for maxillofacial surgery reconstruction was extensively illustrated where CT scans are translated to SPL format. Laser Lines demonstrated an RP system at the meeting (figures 3 and 4). It was reported that RP systems are now being used for limited production runs as well as for prototype development. As an example of the versatility of RP systems, the example of a clock mechanism was demonstrated – complete with frame, moving gear wheels and hour/minute arms. This unit had been produced as a solid structure of both model and support material and with subsequent removal of the ‘support material’.

**BLADDER PRESSURE MEASURING SYSTEM**

Clive Griffiths (Freeman Hospital, Newcastle) described the evolution of the CT 3000 bladder pressure measuring system as currently marketed by Mediplus Ltd. The CT 3000 uses an indirect ‘pressure cuff’ method. Initially agreements were drawn up for the working prototype to be developed externally to RMPD as a MediLink project and then subsequently as a KTP-type project but both of these failed to deliver a working system. With subsequent development work also being undertaken by RMPD, this system was then taken forward as the commercial system with Health Technology Devices funding to undertake multiple site trials. CE marking of the system was taken through Annex IV of the Medical Devices Directive via SGS Yarsley with the technical file being given to an external contractor. An EMC test certificate (EN60601-1-2) and EN60601-1 certificate were supplied by SGS Bowburn. This route to equipment development within the NHS identifies a more open-ended approach which draws upon specialist in-house skills to develop functioning technology within the clinical environment.

**SUMMARY**

The meeting identified that a broad range of skills are required both to manage innovation and intellectual property as well as steer product development through design/manufacture/verification. It is evident also that there are resources allocated to manage innovation within the NHS, and that more effective use of these resources will bring benefits to all involved, including patients as improved treatments are provided. This would also be an opportunity for medical physics to raise its profile as an innovating discipline. It is an observation that existing training schemes within clinical engineering and medical physics as a whole do not adequately support management of innovation.
ON FEELING LIKE AN IMPOSTER

It can take a lot of effort to see the world differently, but sometimes it catches us unawares. Having a Friday off recently, I listened to a physicist on Radio 4’s Desert Island Discs talking about how difficult the academic environment can be for those who put caring for family and children before their own career. The fact that the physicist was a woman did not surprise me. That she is a female Fellow of the Royal Society, which is 95 per cent male, does make her special.

The uneven gender balance in science as a whole is changing slowly but some areas are making considerably faster progress than others. Medical physics and medical engineering is seen as a beacon by the physics and engineering community and IPEM is asked increasingly frequently to provide information on women scientists and engineers. In 2006–07 IPEM carried out a survey across the NHS, contacting heads of department to ask for detailed information on posts and occupants. Returns covered about half the estimated workforce, enough to make broad statements on numbers and workforce characteristics. Overall the gender balance in NHS medical physics and clinical engineering is one-third female to two-thirds male, much higher than in academia or science as a whole. The proportion rises to 40 per cent women in medical physics specialties, with women in the majority in nuclear medicine and clinical measurement. However, 93 per cent of engineering posts are still filled by men with the highest proportion of women in rehabilitation engineering at 12 per cent, falling to 4 per cent in mechanical engineering. And few senior managers are female.

IMPOSTER SYNDROME

The reality behind these statistics forms our underlying attitudes, and that is where a sudden insight can begin a process of change. What challenged me in that radio programme was the sacrifice the physicist’s husband had made to support them both. I had a sudden realisation of what it might mean to balance my own career differently for the sake of someone else, and the pressures, costs and emotions this would bring. Work on gender imbalance highlights how difficult it is to change entrenched culture, so that women can enter male-dominated areas or progress as easily up the career ladder. Attitudes take their toll on individuals through emotions such as guilt or resentment, and also less directly in feelings of inadequacy. This sense of not being up to the job is reportedly more common for successful women and for academics. Professor Cathy Sykes of Bristol University, who is both, recently described research she has carried out into what has been called ‘Imposter Syndrome’.

Individuals with these feelings dismiss proofs of success as due to luck, timing or having deceived others into seeing them as more capable than they are. She found that as many as 70 per cent of us admit to feeling this at some time, and to living with a vague fear of being ‘found out’ which hampers achievement and growth.

Keith Ison
President

As new patterns of behaviour, technologies and organisations emerge so it takes time for underlying values to shift. The strain on us intensifies as life speeds up and we are more likely to feel left behind, inadequate and struggling. An advertising trailer for Formula 1 motor racing echoed this unhelpful mantra: ‘If you think you are in control, it means you aren’t going fast enough.’ The route through this easily induced sense of inadequacy is to be able to accept one’s achievements and, to quote one commentator, ‘be comforted by the fact that everyone else suffers from paranoia, too’. One suggestion is to look at ourselves as if we were a colleague, to bring more objectivity to our opinion of what we do and who we are. Another thought was given to me by a mentor: being able to ‘wing it’ successfully in a broader arena is not always a sign of poor preparation but can be a skill in its own right. Try as well to consciously celebrate your achievements. This is an area where, as a profession, we have some way to go.
WELL DONE EMMA

A

s underlined by Alan Perkins in the last issue of 
Scope, the question of undertaking a PhD is not a 
trivial one. However, taking the decision is the 
easiest part. All those 
who have spent hours writing and 
submitting too often unsuccessful grants 
will know how frustrating and 
discouraging this exercise can be. When 
you finally get the necessary funding, you 
can justifiably be elated, but this is just the 
beginning of a long and often treacherous 
journey. The road ahead is paved with 
endless hours of research, alternating bad 
and good days, abstracts and paper 
submissions, writing your dissertation 
and finally facing the dreaded viva; in 
what appears to be the blink of an eye 
three or four years of your life have 
evaporated. Thanks to the first IPEM 
training fellowship, Emma Bowers (or 
shall I say Dr Emma Bowers) completed 
her journey by successfully defending her 
PhD, so congratulations to her and thank 
you for the article.

In the features, you can also find an 
update on the EMIT and EMITEL by 
Slavik Tabakov. If you want to know what 
sort of risk you’re taking on increasing the 
service interval on your equipment, turn 
to page 24 where you will find an 
excellent piece by Subashini 
Chandrasekarar and Giles Hartley. Dan 
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feedback and ideas to help us improve it 
will be welcome.

Finally, I would like to renew my cry for 
help, we are still short of editors so please 
don’t hesitate to contact us.

Hope you will enjoy this issue.

MARC E. MIQUEL EDITOR-IN-CHIEF
New detection system designed for imaging of superficial vasculature

The non-invasive characterisation of the structure, oxygenation and flow through the vasculature on the surface of the skin is necessary for a variety of clinical applications, including the assessment of skin tumours and soft tissue damage.

Photoacoustic imaging is a new imaging modality that combines the high contrast and spectroscopic-based specificity of optical techniques and the high spatial resolution of ultrasound, and is particularly useful for the imaging of superficial blood vessels. However, the detection of signals can be problematic, as the ideal detector should be transparent, allowing light to be transmitted and ultrasound waves detected at the same point, and the element must be small compared to the acoustic wavelength. Most photoacoustic devices use piezoelectric transducers, which tend to be opaque, and there is an inverse relationship between the active area of the receiver and its sensitivity.

Researchers have designed an entirely new detection system based on a Fabry Perot polymer film interferometer (Phys Med Biol 54: 1035–46). The film is transparent to the frequency of laser light used to excite blood cells, and the returning photoacoustic waves alter the thickness of the sensor, and hence alter the reflectivity. This change is detected by a second interrogating laser which is scanned across the surface of the film, and the photoacoustic waveforms that are detected are then combined to form 3D images. The resolution obtained by the system is limited only by the spot size of the interrogation laser beam.

The team tested the system by imaging vasculature in three locations: a human palm, skin on the abdomen of a mouse, and human colorectal tumours implanted in mice. The results demonstrated that the system can generate images with sub-100 μm resolution at depths of up to 5 mm.

At present, it takes 10–15 minutes to acquire a 3D image, and the researchers hope to reduce the acquisition time in order to make the system into a useable clinical tool. Options include using lasers with higher pulse repetition rates and altering the sensor technology to speed up the read-out of data.

This story was reported on Medical Physics Web on 12th February. Further information can be found using the following link: http://medicalphysicsweb.org/cws/article/research/37760

OCT used to measure flow in diabetic retinopathy

Diabetic retinopathy is a common cause of blindness and occurs due to thickening of the blood vessel walls in the retina, microvascular occlusions, retinal tissue ischaemia and growth of abnormal new blood vessels, leading to loss of functional vision. The method currently used by ophthalmologists to detect retinopathy is fluorescein angiography, which involves injecting dye into the retinal veins and looking for leaks. This is invasive, and has side effects such as nausea and vomiting.

The more severe the retinopathy, the lower the blood flow to the retina, and hence there is interest in developing methods to measure retinal blood flow to facilitate early diagnosis. Optical coherence tomography (OCT) provides high resolution cross-sectional images, and is commonly used in the diagnosis of retinal diseases. In addition to morphological images, OCT can also detect a Doppler frequency shift of reflected light, which provides information on blood flow. Researchers have utilised this technique in a study published in Optics Express (17: 4061–73).

To measure total flow velocity and volume, the angle of incidence between the OCT probe beam and the blood vessel must be known; this is not available from a single cross-sectional OCT image. The team therefore used a double circular scanning pattern (DCSP), which measurements of flow were first made in the retinal branch veins. The difference in radius is chosen so that the blood vessel between the scanning circles has a linear shape, and the positions of the blood vessel in the two Doppler OCT images can be used to determine the angle between the probe beam and direction of blood flow.

A study was conducted on two diabetic patients, one with retinopathy and one without, in which measurements of flow were made in the retinal branch veins. The measured total retinal blood flow was in the range 37.4–49.2 μl/min for the patient without retinopathy, and 30.1–39.6 μl/min for the patient with retinopathy. The results indicate that Doppler OCT is a viable non-invasive method of detecting reduced blood flow in diabetic retinopathy, but a larger clinical trial is required.

This story was reported on physnews.com on 11th March, and further information can be found: http://www.physnews.com/showlink.php?id=10429
First irradiation images obtained using a new linac-MRI system

The image on the left shows MR-linac 1, with radiation, and the image on the right shows MR-linac 2, without radiation.

Real-time imaging during radiotherapy could improve the targeting of tumours in organs that may move, such as the lung, prostate and stomach, and assist in sparing radiation-sensitive organs such as the rectum. MRI is ideally suited for this purpose as it produces images which show good contrast between different types of soft tissue and does not involve the use of further ionising radiation. However, the radiofrequency and magnetic fields from linacs and MR scanners are not compatible with each other, which has so far prevented the development of a hybrid linac-MR system.

In order to resolve the compatibility issues between linacs and MR, a team of researchers at the Cross Cancer Institute in Edmonton, Canada, have redesigned the system ‘from the bottom-up’, and at the end of last year MR images were obtained during irradiation for the first time.

The prototype linac-MR system consists of a 6MV linac mounted on the open end of a biplanar 0.2T MR magnet, with both the linac and magnet on a single gantry that rotates around the patient. The prototype is designed for image-guided radiotherapy of the brain and has a 27 cm opening large enough to accommodate a head, and the team has also begun work on a whole-body system which will have a 70 cm opening.

The design of the system minimises the effect of the magnetic field on the dose distribution, and in cases where small dose perturbations are unavoidable, corrections can be performed using a simple algorithm. Interference in the MR images caused by the linac’s RF field is avoided using a design which is currently confidential, with patents pending.

In a proof-of-concept test, the team used the prototype system to acquire images of an acrylic phantom containing holes of 2.52, 3.45 and 4.78 mm diameter filled with a copper sulphate solution before and during irradiation. The images obtained during irradiation did not show any significant distortions and were similar to those obtained before irradiation, with just a small difference in the signal-to-noise ratio (SNR).

The team has now submitted grant applications to develop the whole-body system, and they hope to begin clinical trials within the next 5 years.

This story was reported on Medical Physics Web on 29th January, and further information can be found using the following links:
http://medicalphysicsweb.org/cw/article/research/37440
http://mp.med.ualberta.ca/linac-mr/index.html

Image credits: ‘MR-linac 1 – with radiation’ and ‘MR-linac 2 – without radiation’ provided by Prof. Gino Fallone, Director, Department of Medical Physics, Cross Cancer Institute, Edmonton, Canada

Safety warning for patches in MRI

On 5th March 2009, the US Food and Drug Administration (FDA) issued a warning related to the risk of wearing transdermal drug patches during MRI scans.

The risk of wearing a patch with a metallic backing during MRI has been well established, but it has recently been found that some patches containing metals such as aluminium, which are often not visible to the user, do not contain an MR safety warning in the product labelling. While not attracted to the strong magnetic field of the scanner, electrical currents can be induced in the metal, which generate heat and can result in burns.

The patches of concern include both brand name and generic products, and patches which can be purchased over the counter without a prescription, including certain types of nicotine patches. The FDA is currently reviewing the labelling and composition of all medicated patches to ensure that those containing metal are accompanied by an appropriate warning.

This story was reported on the FDA News website, and further information can be found using the following links:
http://www.fda.gov/bbs/topics/NEWS/2009/NEW01967.html
http://www.fda.gov/cder/drug/advisory/transdermalpatch.htm

IN BRIEF

VASCULATURE IMAGING
Photoacoustic imaging allows vasculature on the surface of the skin to be imaged and a new detection system has been designed, based on a Fabry Perot polymer film interferometer. The resolution is only limited by the spot size of the interrogation laser beam, and high-quality images have been obtained at depths of up to 5 mm.

IMAGES FROM LINAC-MRI
A linac-MR imaging system has been created by researchers and MR images obtained during irradiation. A prototype is suitable for brain scanning and the researchers are developing a model for whole-body scanning. Clinical trials should begin within 5 years.

OCT MEASURES RETINAL FLOW
Reduced blood flow to the retina causes a loss of vision for patients with diabetic retinopathy. Optical coherence tomography has been used to measure blood flow in the retina to detect and diagnose this condition. The benefit of this technique is that it is non-invasive and therefore produces no side effects for the patient.

PATCH SAFETY IN MRI SCANS
A warning has been issued regarding wearing transdermal medical patches during MRI scans. Some patches contain metals and do not have a safety warning on the product so could potentially cause heat injury during scans.
Congratulations to the following who has recently been successful in the IPEM Viva Voce examinations for the Clinical Technology Diploma of IPEM [DipIPEM(T)].

<table>
<thead>
<tr>
<th>Name</th>
<th>Training Centre</th>
<th>Result</th>
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<tbody>
<tr>
<td>Mr Amran Saddiq</td>
<td>Oxford</td>
<td>Pass with Merit</td>
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Congratulations to the following who have recently been successful in the IPEM Viva Voce examinations for the Clinical Science Diploma of IPEM [DipIPEM(S)].

<table>
<thead>
<tr>
<th>Name</th>
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<tr>
<td>Mr Simon Atkins</td>
<td>London North</td>
<td>Pass with Merit</td>
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<tr>
<td>Mr Michael Austin</td>
<td>Merseyside</td>
<td>Pass with Merit</td>
</tr>
<tr>
<td>Mr James Burnley</td>
<td>West Midlands</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Thomas Butterfield</td>
<td>Sheffield</td>
<td>Pass</td>
</tr>
<tr>
<td>Miss Elizabeth Chaloner</td>
<td>London South</td>
<td>Pass</td>
</tr>
<tr>
<td>Miss Anna Coombs</td>
<td>Northern England</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr James Daniel</td>
<td>Northern England</td>
<td>Pass</td>
</tr>
<tr>
<td>Miss Hannah Dodgson</td>
<td>London South</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Paul Drewell</td>
<td>Scotland</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Martyn Gilmore</td>
<td>Northern England</td>
<td>Pass</td>
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<tr>
<td>Mr Laurence King</td>
<td>South West</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Garry McDermott</td>
<td>Oxford</td>
<td>Pass</td>
</tr>
<tr>
<td>Miss Kim McDonald</td>
<td>Scotland</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Dominic Nolan</td>
<td>South West</td>
<td>Pass</td>
</tr>
<tr>
<td>Miss Rachel Norris</td>
<td>Manchester</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Emmanouli Papadopoulos</td>
<td>Hull</td>
<td>Pass</td>
</tr>
<tr>
<td>Miss Geraldine Revill</td>
<td>London North</td>
<td>Pass</td>
</tr>
<tr>
<td>Miss Nicole Scrivener</td>
<td>Hull</td>
<td>Pass</td>
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<tr>
<td>Ms Magdelana Skikiewicz</td>
<td>Scotland</td>
<td>Pass</td>
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<tr>
<td>Mr Martin Smith</td>
<td>Oxford</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Simon Stevens</td>
<td>Surrey and South West London</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Jonathan Taylor</td>
<td>Northern England</td>
<td>Pass</td>
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<tr>
<td>Mr Cesar Tinoco</td>
<td>Kent</td>
<td>Pass</td>
</tr>
<tr>
<td>Mr Michael Trainer</td>
<td>Hull</td>
<td>Pass with Merit</td>
</tr>
<tr>
<td>Dr Gillian Whitenett</td>
<td>Scotland</td>
<td>Pass</td>
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And don’t forget to register for the Annual Scientific Meeting, 14th–16th September 2009, University of Liverpool.

**DIARY OF MEETINGS 2009**

<table>
<thead>
<tr>
<th>Meeting</th>
<th>Dates</th>
<th>Venue</th>
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<tr>
<td>Mammography Physics Training Meeting</td>
<td>6th–8th July</td>
<td><strong>Aston University, Birmingham</strong>&lt;br&gt;This 3-day meeting will take place at Aston University in Birmingham on 6th–8th July 2009</td>
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<tr>
<td>Codes of Practice Study Day</td>
<td>14th July</td>
<td><strong>National Physical Laboratory, Teddington</strong>&lt;br&gt;In the UK, primary dosimetry standards are cascaded to radiotherapy centres via implementation of national codes of practice. The aim of this meeting is to review their theoretical basis and clinical application. Registration deadline: 1st July 2009</td>
</tr>
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</table>

And don’t forget to register for the Annual Scientific Meeting, 14th–16th September 2009, University of Liverpool.
In this new section, we will list international courses, conferences and funding calls of interest to the IPEM community. Important news on overseas medical physicists’ and clinical engineers’ work will also appear here. As we are still finding our feet, we encourage you to send comments and feedback to the international editors. If you would like to submit an item just drop us an email.

### COURSES

<table>
<thead>
<tr>
<th>Course</th>
<th>Venue and Dates</th>
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### CONFERENCES: EUROPE

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<th>Conference</th>
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### CONFERENCES: NORTH AMERICA

<table>
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<tr>
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<tr>
<td>AAPM Annual Scientific Meeting</td>
<td>Anaheim, CA, USA, 26th–30th July 2009</td>
<td><a href="http://www.aapm.org/meetings/09AM/">http://www.aapm.org/meetings/09AM/</a></td>
</tr>
<tr>
<td>Canadian Association of Radiation Oncology Annual Meeting</td>
<td>Quebec City Quebec, Canada, 30th September–3rd October 2009</td>
<td><a href="http://www.caroacro.ca/Meetings___Education/Annual_Scientific_Meetings/23rd_Annual_Scientific_Meeting_September_30___October_3__2009___Quebec_City.htm">http://www.caroacro.ca/Meetings___Education/Annual_Scientific_Meetings/23rd_Annual_Scientific_Meeting_September_30___October_3__2009___Quebec_City.htm</a></td>
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### CONFERENCES: REST OF THE WORLD

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<th>Conference</th>
<th>Venue and Dates</th>
<th>More information</th>
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### SURVEYS

SEDENTEXCT is a project funded by the EU’s 7th Euratom framework to enhance the safety and efficiency of dental cone beam CT. Part of the project is to involve all stakeholders, e.g. manufacturers, dentists, radiologists and medical physicists, in developing a website to disseminate impartial information, structured training and evidence-based clinical guidelines.

As publicised in a December IPEM newsletter, the SEDENTEXCT project is currently undertaking a survey of diagnostic radiology medical physicists and technologists throughout Europe to establish what information you would like to see on the website.

If you haven’t had a go already, can I ask you to take 10 minutes to complete the survey, found at [http://www.sedentexct.eu/surveyphys](http://www.sedentexct.eu/surveyphys). Even if you haven’t seen a dental cone beam set yet, one is likely to be coming your way soon so please voice your opinion on what help and information you would like to see being made readily available.

### GUIDELINES

You might also be interested in the consensus guidelines of the European Academy of Dental and Maxillofacial Radiology, ‘Basic Principles for the Use of Dental Cone Beam CT’, just published on the SEDENTEXCT website: [http://www.sedentexct.eu/basicprinciples](http://www.sedentexct.eu/basicprinciples)
In this issue Julian Minns investigates problems of assessing the impact of medical devices in his review of *Medical Technology into Healthcare and Society: A Sociology of Devices, Innovation and Governance* by Alex Faulkner, and we have also included a review of *Advances in Medical Physics 2008*.

Two Popular Science books are reviewed, both authored by familiar names. The first by journalist and doctor Ben Goldacre, the second by presenter and theoretical physicist Michio Kaku. Just Published presents to you a clutch of books, both new and second editions, that are soon due to go on sale. If you are interested in reviewing these or any other books, please get in touch.

Avid readers of the column may be sad to note that Sarah Misson-Yates will shortly be stepping down; she has done a fantastic job of coordinating book reviews for almost 3 years. If you’d like to try your hand at being a Scope Book Review Editor, please contact the Editor-in-Chief, Marc Miquel.

Gemma Whitelaw and Sarah Misson-Yates

**Medical Technology into Healthcare and Society**

I found this an interesting sociological thesis on the problems of assessing the impact of medical devices used in clinical practice. Five examples of very differing technological developments highlight the problems encountered in undertaking comparative assessments is an interesting exercise.

It is difficult to read, with a significant amount of sociologist’s terminology which takes some time to digest. An example from page 2: ‘Evidence-based healthcare should be conceptualised as a phenomenon of political regulation and social legitimisation as well as a scientific movement’, which is similar to the three preceding sentences enriched with similar jargon.

The one thing the author does highlight to me is the plethora of agencies which overlap in their remits, policies, regulatory and safety aspects of device development and usage. This is emphasised in the chapter on infusion pumps: ‘an All-Party parliamentary Group for Patient Safety was established... the guidance agency NICE is conspicuously absent from this group’ (although NICE is not directly involved with patient safety monitoring). There is also a confusion within the book about the definitions and roles of all these agencies which change throughout.

As an example, in one chapter NICE is described as a technology appraisal and healthcare guidance agency and in another as a regulatory agency (which it is not!).

Despite this, I enjoyed the chapters relating to the problems of audit, governance and patient safety; and the inherent risks of mis-use of the five devices covered artificial hips, PSA testing for prostate cancer, infusion pumps, coagulometers and the governance of tissue engineering.

Primarily, this book is aimed at the healthcare technology assessment professionals and researchers involved with the governance and socio-economic issues of devices, rather than clinical scientists involved with the development and performance of these devices.

**Julian Minns**

**Newcastle General Hospital**

**MEDICAL TECHNOLOGY INTO HEALTHCARE AND SOCIETY: A SOCIOLOGY OF DEVICES, INNOVATION AND GOVERNANCE**

ALEX FAULKNER

Published by: Palgrave Macmillan (2009)
Language: English
Hardcover, 272 pages
List price: £50.00

**Advances in Medical Physics 2008**

This book, the second in a biennial series, discusses a broad range of techniques within imaging, radiotherapy, engineering and statistics and is a valuable addition to the usual medical physics texts found on our shelves. As the title suggests, it addresses many of the technical areas which usually require considerable research in journals or via the internet. Important concepts such as an MRI update build upon current common experience but there are other chapters such as Health Risks of Exposure to Low Doses of Ionizing Radiation which open up discussions that are becoming increasingly relevant to those in medical physics.

Other chapters, such as Chapter 17 on Some Perspectives and Insights from Modern Statistical Modelling, extend the text from purely being of use to those involved with medical physics and would attract the attention of mathematicians, computer scientists and statisticians, and this consolidation of professions is a very valuable aspect of this book. An unusual final chapter discusses the management of grants and their application process and since the book is American, many readers would assume that the chapter is of limited relevance to them, but in fact the comments and observations made are easily transposed to the UK/European bodies which again makes the chapter unusual in subject matter but very valuable in its own right.

All of the chapters are supported by extensive references although in places the references might be considered a little old. Nevertheless the references do readily permit further investigation should the reader so desire.

There are two slightly negative observations. Firstly, it would be useful to have a more comprehensive approach to the content in that there is very little on MRI or a multitude of other medical physics subjects which exist. It would clearly be an impossible task to comprehensively summarise the whole of physics and engineering but some indications of parallel texts or intensions for future volumes would be helpful. Secondly, whilst understandable, it is also occasionally inconvenient for the text to refer specifically to American standards and working practice and the reader should be familiar to areas where the UK and USA differ.

Overall, this book is highly recommended as an addition to your bookshelves.

**Malcolm Sperrin**

**Royal Berkshire NHS Trust**

**ADVANCES IN MEDICAL PHYSICS 2008**

ANTHONY B. WOLBARST, KENNETH L. MOSSMAN AND WILLIAM R. HENDEE

Published by: Springer (2008)
Language: English
Hardcover, 386 pages
List price: US $94.00
Bad Science

Ben Goldacre, or to give him his full title, Dr Ben Goldacre, is an award-winning writer, broadcaster and medical doctor. He studied medicine at Oxford and UCL and now works full time for the NHS in London. Ben appears regularly on TV and Radio 4, and has written for the *Guardian*, *Time Out*, *New Statesman* and the *British Medical Journal*.

The book *Bad Science* has been adapted from a collection of articles written for his weekly ‘Bad Science’ column in the *Guardian*. Its aim is to set straight much of the damage done by scaremongering journalists, bogus health professionals, pseudoscientific cosmetic adverts and large pharmaceutical companies.

The book has a strong medical bias and, as scientists and engineers in the healthcare industry, we will no doubt be familiar with some of the topics covered. Who amongst us hasn’t been amused by claims made in magazines or on TV about the latest wonder pill, fad diet or detox regime? In this book Ben names and shames some of the guiltiest perpetrators of bad science such as Dr Gillian McKeith PhD or, to give her full medical title, Gillian McKeith, to whom he devotes a whole chapter.

Other chapters are dedicated to homeopathy, the placebo effect, bad statistics and various health scares/cures.

Many of the topics in the book are presented in a humorous manner and one might well think ‘what’s the problem?’ If people think that Hopi ear candles or sugar pills are doing them some good, does it really matter if they don’t stand up to scientific scrutiny? However, some of the examples demonstrate how the media can totally misinterpret (whether deliberately or unwittingly) scientific research to deliver exaggerated or false messages to the public. One such example is explored in the book’s final chapter, ‘The Media’s MMR Hoax’, which looks at how the combined MMR vaccine and its link with autism came to be one of the most controversial health stories in recent years. The chapter examines the evidence behind the media’s scare story and asks the reader to draw their own conclusions on the matter.

This book is a real eye opener and reveals just how badly science is portrayed to the public. Ben is not afraid to speak out and openly welcomes his critics to engage in debate. The sections relating to research made me examine my own scientific methods and I encourage anyone in the scientific community to do the same.

On the downside the intelligence of the reader was sometimes underestimated. For instance at one point in the chapter ‘Why Clever People Believe Stupid Things’, Ben states that he’d be ‘genuinely intrigued to know how long it takes to find someone who call tell you the difference between “median”, “mean” and “mode” from where you are sitting right now’. Working in a medical physics department, I think it would take about 5 seconds!
However, putting facetious remarks aside, I believe the book strikes a good balance of light-hearted humour, real and alarming examples of bad science in action and hopefully the tools to uncover the truth for ourselves. The take-home message is don’t believe everything you read, though I would recommend reading this book and then passing it on to your friends and family!

To keep up-to-date with Ben Goldacre’s tireless crusade against the poor interpretation and portrayal of science in the media I also recommend you visit his website (http://www.badscience.net/) which has links to his numerous newspaper articles, details of talks he is giving and a forum for those interested in debating for or against Ben’s views.

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BAD SCIENCE
BEN GOLDACRE
Published by: HarperPerennial [2009]
ISBN: 9780007284870
Paperback, 288 pages

Physics of the Impossible

“To infinity and beyond!” Since the 1940s we have all grown up surrounded by the weird and wonderful world of science fiction. From the early days of comic books and superheroes TV series, to the explosion of Japanese cartoons and the regular Hollywood blockbusters, successive generations have marvelled at spaceships, time travel, deathly phasers, noble light sabres or amazing teleportation devices. Although the (at the time) miraculous automatic doors of the early Star Treks are now in every supermarket, most of the technology on display firmly belongs to the imaginary world.

Sci-fi had, and still has, an influence on a lot of people, from nerds spending their days in specialised shops to inquisitive kids trying to understand the science behind the fiction. Michio Kaku is one of the latter; from a young age he decided to embark on a career in theoretical physics and later on, through his books and TV series, teacher to the masses. In his latest offering, he tackles the science behind the wondrous technology of the sci-fi and fantasy universe.

From shields to faster-than-light travel, invisibility cloaks to perpetual motion machines, he carefully looks at the science and technology to bring these ‘impossible’ marvels to life. The book is divided into three levels of impossibility: class 1 should become reality on Earth in a not-too-distant future; class 2 are probably achievable (or achieved) by very advanced civilisations, and class 3 break the (current) laws of science. As an obvious Trekkie one can regret he did not call his categories B’lena (“Captain it would take me years to create this!” Janeway: “You have 5 minutes or we will all be dead”), Spock (“It is technology but not as we know it”) and Scottie (“I cannot break the law of Physics!”).

Despite flirting with oversimplification on a couple of occasions, the author manages to explain how and why most of the arsenal of the sci-fi heroes and baddies could be created, at least in modified forms. More than the knowledge that shields and phasers could just be around the corner, the encouraging message is that very little is theoretically impossible but unfortunately most is practically inaccessible to us technology-retarded earthlings. After all, our level 0 technological civilisation is only a few hundred years ahead of our chimp cousins.

Marc E. Miquel

PHYSICS OF THE IMPOSSIBLE
MICHIO KAKU
Published by: Allen Lane [Penguin Books]
ISBN: 970-0-713-99992-1

Just Published!

The Physics of Medical Imaging by Steve Webb (Taylor & Francis Ltd). This second revised edition is launched in July this year and will provide a good update to this favourite text. For those unfamiliar with the first edition, The Physics of Medical Imaging reviews the scientific basis and principles behind a range of imaging modalities.

Handbook of Photonics for Biomedical Science by Valery V. Tuchin (Taylor & Francis Ltd). From the Medical Physics and Biomedical Engineering series, this 1,000-page book provides a quick reference for those interested in the use of lasers and light therapies in the clinical setting.

Nuclear Medicine Imaging Physics by Joao Jose De Lima (Taylor & Francis Ltd). This imaging book focuses on nuclear medicine and covers all aspects of the process. Written at a level suitable for the recent graduate and covering all of the basics and more, this book would be an excellent teaching resource.

Recent Advances in the 3D Physiological Human by Nadia Magnenat-Thalmann, Jian J. Zhang and David Dagan Feng (Springer London Ltd). This fascinating area focuses on the creation of patient-specific computer models for personalised healthcare. This volume looks at the evolution and the improvement of technological devices such as scanners and medical instruments to see how they have helped in our understanding of the human body and its functionalities.

The book is divided into three parts: anatomical and physiological modelling, physically-based simulation, and medical analysis and knowledge management.

Digital Mammography by Ulrich Bick and Felix Dietmann (Springer-Verlag). This state-of-the-art reference book provides in-depth coverage of all aspects of digital mammography and compares and contrasts the benefits of digital mammography with other imaging modalities. Writers from both North America and Europe allow interesting geographical perspectives into practice differences. Suitable for newly qualified and seasoned professionals.

Biomedical Engineering for Global Health by Rebecca Richards-Kortum and Michele Follen (Cambridge University Press). This empowering book aims to inspire engineers to help make bioengineering a global issue and close the gap in life expectancy between rich and poor. It aims to educate engineers about problems with biomedical technology in the developing world. The highly-praised book addresses biomedical engineering from a truly global perspective and shows students how important these issues are.

Computed Tomography by Willi A. Kalender (John Wiley). Published in September, this book presents all aspects of CT from conventional single-slice acquisitions to volume acquisition with multi-slice and cone-beam spiral CT. Aimed at professionals who work daily, regularly or even only occasionally with CT: physicians, radiographers, engineers, technicians and physicists. It comes with a CD-Rom full of case studies and examples. A glossary is also included describing all the important technical terms in alphabetical order.

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