

University of Southampton Research Repository ePrints Soton

Copyright © and Moral Rights for this thesis are retained by the author and/or other copyright owners. A copy can be downloaded for personal non-commercial research or study, without prior permission or charge. This thesis cannot be reproduced or quoted extensively from without first obtaining permission in writing from the copyright holder/s. The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the copyright holders.

When referring to this work, full bibliographic details including the author, title, awarding institution and date of the thesis must be given e.g.

AUTHOR (year of submission) "Full thesis title", University of Southampton, name of the University School or Department, PhD Thesis, pagination

UNIVERSITY OF SOUTHAMPTON

School of Electronics and Computer Sciences

**Design of a Prototype Human Computer
Interface for Serial Neurological Examination in
Patients with Spinal Injuries**

By

Matthew Stenning MBBS MRCS (Eng)

Thesis for the degree of Master of Philosophy

June 2009

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

SCHOOL OF ELECTRONIC AND COMPUTER SCIENCES

Master of Philosophy

DESIGN OF A PROTOTYPE HUMAN COMPUTER INTERFACE FOR SERIAL
NEUROLOGICAL EXAMINATION IN PATIENTS WITH SPINAL INJURIES

By Matthew James Stenning

Patients admitted with spinal injuries following trauma require careful serial examinations to detect any neurological deficit that may develop. Thorough documentation of the findings is of paramount importance. Enforced working practice within the NHS means that these patients are often assessed by different members of staff with varying levels of experience, thus inconsistent documentation can be a cause for concern.

The project aim was to design a Human Computer Interface to standardise the performance and documentation of serial neurological examinations in patients with spinal injury, allowing the user to accurately detect any neurological deterioration.

A prototype system was developed for ward based PC's incorporating the essential requirements of the neurological examination. Usability testing was performed on the prototype by recruiting fifteen users who would be expected to routinely perform the neurological examination on spinal injury patients. Usability was defined by a number of well defined goals (impression, efficiency, learnability, memorability, safety and effectiveness) and methods used in the evaluation included direct observation during completion of tasks, a questionnaire and unstructured interview.

Both quantitative and qualitative data was collected. This data was subsequently analysed using descriptive and inferential methods. The results of the analysis showed that the users responded favourably to the prototype in respects to the all usability goals except efficiency. This lack of efficiency was expected due to the rigid nature of computer based systems compared to paper based methods of recording data but this disadvantage was more than compensated for by the increased patient safety that the system would provide.

It can be concluded from the usability testing that the prototype achieves the aims of the project but further work is required in developing the prototype into a final interface design before beta testing in a clinical environment can be considered.

List of contents

DECLARATION OF AUTHORSHIP	6
1 Introduction.....	8
2 Background.....	9
2.1 Injuries to spinal column, cord and spinal nerves.....	9
2.1.1 Spinal Column Fractures	9
2.1.2 Spinal Cord Injuries	9
2.1.3 Pathology of Spinal Cord Injury	10
2.1.4 Management of patients with Spinal Injuries	12
2.1.5 Spinal Nerve Pathology	15
2.2 Pressures within the NHS	16
2.2.1 The lack of specialist injury centres	16
2.2.2 Difficulties with the team approach.....	16
2.2.3 Working time directive	17
2.3 Standard of examination and note keeping.....	20
2.3.1 Differing Standards in examination.....	20
2.3.2 Standards of note keeping.....	22
2.3.3 Surveys looking at the technique of examination and record keeping of 4 – 5 doctors asked to do a neurological examination on a patient	22
3 Technical Chapter.....	26
3.1 Learning using Information technology	26
3.1.1 E-Learning	26
3.1.2 Goals of E-Learning	27
3.1.3 Blended Learning.....	27
3.1.4 M-Learning	28
3.2 Use of information technology in clinical practice.....	28
3.2.1 As an educational tool	28
3.2.2 As a research tool.....	29
3.2.3 As a tool in the clinical setting	30
3.3 Hardware availability in the NHS.....	33
3.3.1 PC desk top	33
3.3.2 High definition screens	34
3.3.3 Bed side computers.....	34
3.3.4 Mobile Devices	34
3.4 Summary.....	35
4 Design Chapter	36
4.1 Objective of research	36
4.2 Objectives Statement	36
4.2.1 How the HCI is expected to affect the target persona's	37
4.3 The basis of HCI design	38
4.3.1 Interaction design.....	38
4.3.2 The process of interaction design	39
4.3.3 The use of prototypes in interaction design	39
4.4 The steps taken in the HCI design	41
4.4.1 Identifying user needs and establishing requirements	41
4.4.2 Developing a design that meets with the user requirements.....	44
4.4.3 Building an interactive version of the design	48
4.4.4 The interactive prototype	49

4.4.5	Evaluation of the system.....	54
5	Evaluation chapter	55
5.1	Background.....	55
5.1.1	Techniques of user assessments.....	55
5.1.2	Usability Goals	57
5.2	Evaluation techniques used to evaluate the designed HCI.....	58
5.2.1	Predictive modelling during the design process	58
5.2.2	Evaluating the users.....	58
5.3	Results	59
5.3.1	User demographics	59
5.3.2	Usability goal analysis	60
5.3.3	Qualitative results – User comments	63
5.4	Discussion.....	64
5.4.1	Authors initial impression.....	64
5.4.2	User Opinions – Quantitative data.....	64
5.4.3	Usability Goals – Quantitative data.....	66
5.4.4	Usability goals – qualitative data.....	67
5.5	Summary.....	70
6	Conclusions and future works	71
6.1	Conclusions	71
6.2	Future work.....	71
6.2.1	How the interface displays information to the user.....	71
6.2.2	Hardware availability.....	72
6.2.3	Prototype evolution.....	73
6.2.4	Further evaluation	73
7	Appendices	74
7.1	Appendix 1: Pictorial Demonstration of Brown-Sequard Hemisection and Central Cord Syndrome.....	74
7.2	Appendix 2: The Asia Chart.....	75
7.3	Appendix 3: Patient Questionnaire.....	76
7.4	Appendix 4: Example of Chart Given to Junior Doctors to Test Anatomical Knowledge 77	
7.5	Appendix 5: Possible Case Scenarios.....	78
7.6	Appendix 6 – User questionnaire	83
	Additional comments about your feeling or emotions when using the software:-	83
	Additional comments about whether you feel in control:-	84
	Additional comments about how easy you felt the software was to become familiar with:-	84
	Additional comments about how helpful the system is in assisting you resolve a situation:-	85
	Additional comments about how effective you feel the software was:-	85
7.7	Appendix 7 – Raw data collected from user evaluation	86
8	References.....	87

List of tables and illustrations

Table 1: Timetable for Implementation of the EWTD for Junior Doctors: pg 18

Table 2: The MRC muscle power grading system: pg 21

Table 3: User Demographics: pg60

Table 4: Mean values for usability goals: pg62

Table 5: Student t-test results on data: pg 63

Table 6: Most common user comments regarding the prototype: pg63

Figure 1: Would you prefer just 1 doctor to be responsible for your care on admission to hospital? : pg 20

Figure 2: Do you think that the doctor patient relationship is important? : pg 20

Figure 3: Anatomical knowledge of the junior doctors: pg 23

Figure 4 – User scores regarding usability of the prototype: pg 61

Figure 5 – Scores for each usability goal: pg62

DECLARATION OF AUTHORSHIP

I, Matthew James Stenning

declare that the thesis entitled

Design of a Prototype Human Computer Interface for Serial Neurological Examination in Patients with Spinal Injuries

and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- none of this work has been published before submission

Signed:

Date:.....

Acknowledgements

I would like to acknowledge the work performed by Mr C Hargood, research student at the Electronic and Computer Sciences School, Southampton University, on the coding required to construct the prototype interface.

Abbreviations

ASIA	American Spinal Injuries Association
CPRS	Computer based Patient Recording System
ECS	Electronic and Computer Science
ENT	Ear Nose and Throat
EWTD	European Working Time Directive
HCI	Human Computer Interface
MRC	Medical Research Council
NHS	National Health Service
PDA	Personal Digital Assistant
SHO	Senior House Officer
SCIWORA	Spinal Cord Injury Without Radiological Abnormality

1 Introduction

The management of injuries to the spine is complex. Injuries can involve the bony spinal column, the spinal cord, the spinal nerves or any combination of the three. The care should involve a multidisciplinary team including doctors, nurses and physiotherapists. A patient who initially presents with no neurological deficit may deteriorate and therefore repeat assessments of the patient are required. Working pressures within the NHS mean that patients are often assessed by different members of staff with varying experience. The attention to detail when documenting assessment findings are therefore paramount, in order to assist a staff member who may be examining the patient for the first time in the middle of the night because the patient has deteriorated.

There are some charts in use such as the American Spinal Injuries Association (ASIA) chart which helps standardise the examination and documentation of the findings but like most medical recording within the NHS these are paper based. With the ongoing development of computer based systems for medical recording and human computer interfaces it is only a matter of time before the paper based systems can be replaced. The aim of this project is to design such a human computer interface to help standardise the examinations in patients with spinal injuries and in doing so reduce the incidence of complications that may occur if deterioration in a patient's neurological condition is missed.

2 Background

This chapter provides the medical, organisational and political background to the project.

2.1 Injuries to spinal column, cord and spinal nerves

Injuries to the “spine” can involve the bony skeleton, known as the spinal column, or the nervous structures which includes the spinal cord and spinal nerves.

2.1.1 Spinal Column Fractures

Fractures to the spine are common injuries, with an incidence in a complete population of 64 per 100,000 (1). 73% of the patients in this study had injuries to the thoracic or lumbosacral spine, the rest being in the neck (cervical spine). There were two peaks of incidence, young men and elderly women.

There is usually a history of high impact trauma with injuries to the spinal column, 65% are the result of road traffic accidents or falls from height. Less common causes are the result of athletic participation, especially contact sports or as a result of acts of violence.

The incidence of neurological injury associated with spinal fractures varies depending on the region of the spine that is injured. A cervical fracture is associated with a neurological injury in 40% of cases, in the thoracolumbar spine the incidence is 15-20% (2, 3).

2.1.2 Spinal Cord Injuries

A spinal cord injury is a devastating sequelae to a spinal column fracture. There are few conditions as disabling to the individual, causing both physical and psychosocial problems. The effects of these injuries also extend beyond the individual, impacting heavily on the immediate family and society in general.

The annual incidence in the UK of spinal cord injury is estimated at 19 per million (4). These are injuries which affect a young and healthy population with the maximal age risk being 15 – 34 years. Approximately 50% of these injuries occur in road traffic accidents with the other major causes being falls (25%) and sports injuries (10%) (5)

The physical injury often means permanent paralysis of limbs leading to paraplegia or tetraplegia. Half of the spinal cord injuries in the UK are cervical (4), which means as well as the limb paralysis there is also involvement of multiple body systems such as the

respiratory system, the urinary system and the gastrointestinal tract, all of which have their own management problems. The psychological issues for the patient must not be forgotten and can include the loss of independence, poor body image and relationship difficulties.

The financial cost of these injuries is considerable, with loss of earning capabilities as well as the cost to society for the care of these patients. It has been estimated that the annual cost in the UK for spinal injuries is in excess of 500 million pounds (6).

2.1.3 Pathology of Spinal Cord Injury

Injuries to the spinal cord in an individual can be classified as primary and secondary.

2.1.3.1 Primary Injury

The primary injury to the cord occurs at the time of the original insult. As discussed above this is usually the result of high energy trauma. The goal of treatment for primary injuries is education and prevention. A classic example is the effect that the compulsory use of seat belts in vehicles has had on the number of deaths and injuries in road traffic accidents. Since the wearing of a seatbelt in the front of a vehicle became law in 1983 in the UK, it is estimated that 50,000 lives (7 per day) have been saved and 590,000 serious casualties, including potential spinal column fractures and spinal cord injuries, have been prevented (7).

The neurological presentation of the primary spinal cord injury depends upon the site and extent of the injury (8). Described below are the main patterns of spinal cord injury. In practice the presentation is often a mixture of these classic patterns:-

Spinal Cord Transection

In cord transection there is loss of function of all motor and sensory pathways. The motor deficit is initially flaccid with absent tendon reflexes. This is the period of “spinal shock” which in humans usually lasts between two and six weeks. After this period the classic upper motor neuron pattern of hypertonia and hyperreflexia occurs. The sensory deficit is usually complete, with a sensory level corresponding to the spinal level injured.

The spinal cord ends at the upper lumbar spine and so injury to the spinal column below this can damage the spinal nerves causing long term flaccid paralysis and absence of reflexes, a lower motor neuron pattern.

Complete transection of the cord can also occur without evidence of bony fracture or subluxation. This syndrome is known as spinal cord injury without radiographic abnormality (SCIWORA). It occurs in individuals who have a hypermobile spine and suffer a high energy flexion or extension injury. Children are the group who most often present with this syndrome.

Brown-Sequard Syndrome – Appendix 1

This syndrome describes a cord hemisection. It is most often the result of penetrating trauma to the spinal cord. There are classical clinical findings because of the consistent anatomy of the motor and sensory pathways in the spinal cord. . The patient will exhibit ipsilateral motor weakness (corticospinal tract) and loss of fine touch, vibration and joint position sense (dorsal columns). There will also be contralateral loss of pain and temperature sensation (spinothalamic tract).

Central Cord Syndrome – Appendix 1

This syndrome is seen where there is pre-existing stenosis of the spinal canal. The injury results in contusion to the central aspects of the cord. There is often no associated bony injury or subluxation. The motor fibres to the upper limbs are more centrally placed within the corticospinal tracts compared to the lower limbs, this means that in central cord syndrome, the patient presents with marked weakness in the upper limbs compared to the lower limbs. The sensory changes seen are patchy because of the peripheral positions of the sensory tracts.

2.1.3.2 Secondary Injury

The main aim of hospital care of spinal cord injuries is the prevention of the secondary injury. The secondary injury can be described as further injury to the spinal cord that has occurred after the primary injury. These secondary injuries can be the result of further physical damage, such as in poor handling of the patient with a known spinal injury or injuries to the spinal column that are missed at presentation. Training of all personnel who will be involved in the care of these patients now includes courses such as Advanced

Trauma Life Support(9) and manual handling techniques, so that staff are aware of the risks and therefore incidents of further injury or missed diagnoses are avoided.

Secondary injury processes also includes the loss physiological control that the patient may experience. Neurogenic shock is the term used to describe the body's response to the loss of sympathetic control. This response occurs in cervical and high thoracic injuries. With this loss of vasomotor control, significant hypotension occurs. The patient will also develop a bradycardia due to the unopposed action of the vagus nerve. With out appropriate medical support, this will lead to poor perfusion of the cord and subsequent ischaemia and hypoxia of the neural tissues.

Following the primary injury, there is already a zone of critical ischaemia within the cord at the injured level (4). If there is poor control of the subsequent neurogenic shock, leading to ischaemia and hypoxia of the neural tissues, this zone of critical ischaemia can extend in the acute phase to involve a larger region of the cord. Extension of the spinal cord damage of even one level can have a dramatic effect on the patient's prognosis. This can be particularly important in the cervical spine, where for example the difference between a C6 lesion (some remaining shoulder and arm function) and a C5 lesion (no shoulder or arm function) is very substantial in terms of independent living.

It is therefore imperative that in prevention of the secondary injury to the spinal cord, the maintenance of a stable physiology is achieved. It is recommended that the systolic blood pressure should be maintained at 90-100mmHg, the urine output maintained above 30 mls per hour (urine output is a very sensitive indicator of adequate tissue perfusion) and oxygen saturation of the blood be maintained above 95% (4).

2.1.4 Management of patients with Spinal Injuries

2.1.4.1 Regional Spinal Centres

People who sustain a spinal cord injury require specialised care and rehabilitation (4). Within the NHS there are eleven regional spinal centres (8 in England and 1 each in Scotland, Wales and Northern Ireland). These centres would prefer that all patients with spinal cord injury are transferred directly to the regional centre from the Accident and Emergency department. This is because it has been shown that the initial management of a patient with a suspected spinal cord injury can have major implications for the long

term management (10). If transfer to the local spinal injury centre is not possible then the admission to the local orthopaedic or neurosurgical department is required. This means that staff in these hospitals must be able to look after patients with spinal cord injuries until transfer to a spinal injuries centre occurs.

2.1.4.2 The Multi-disciplinary Team Approach (Personas)

A team approach is required for the management of spinal cord injury patients, in order to address the wide range of physical and psychosocial problems that occur. Each member of the team has a specific role in the overall care but significant overlap occurs. The team approach should be the same in the regional spinal centre or the general hospital. The following personas are examples of members of the team that would be expected to look after a spinal injury patient.

Persona 1: Consultant

The consultant has the ultimate responsibility for the patient. They will be the most experienced medically trained member of the team and have the expertise required to manage the patient safely. The consultant will be expected to make the major medical decisions either on their own or in conjunction with other consultants.

Persona 2: Specialist Registrar

The specialist registrar (SpR) is a doctor who is in training to become a consultant in a specific speciality. Each individual will have been practicing medicine for a number of years, having progressed through their basic training as junior doctors. The registrar training takes between four to six years and therefore there will be a varying degree of experience between individuals in this group with respect to their chosen speciality.

The function of the SpR within the team is to act as a liaison for the consultant over the day to day management of the patients and to be senior support to the more junior team members who will have a more limited experience.

Persona 3: Junior medical staff

The junior medical staff includes all doctors below the SpR. There will often be more than one in each team. The amount of experience will vary greatly between individuals, ranging from a senior senior house officer (senior SHO's) who are waiting to progress to the SpR training to a Foundation 1 doctor who has only just qualified from medical school. The juniors are responsible for the day to day 24 hour medical care for the patients and keeping the consultant and SpR aware of any changes in the patient's conditions.

Persona4: Nursing staff

Like the junior medical staff, the experience of the nursing staff will vary greatly, ranging from experienced nursing sisters to newly qualified nurses. The nursing staff have the main responsibility of the general day to day care of the patient. Due to the amount of time spent with the patient the nurse will often be the most likely member of the team to be in the position to identify deterioration in that patient.

Persona 5: Physiotherapists

The physio is responsible for multiple aspects of care. Included are respiratory support with chest physiotherapy, strengthening of the parts of the musculoskeletal system that still function and maintaining mobility in the joints that have lost function in order to prevent contracture.

The above personas are not an exhaustive list of the team members.

There are large group of differing specialities required in the care of spinal injury patients. These team members will often have less frequent involvement with the patient. Occupational therapists deal with the issues regarding the ability of the patient to perform daily living tasks. Speech and language therapists may be required if the cord is injured in the cervical region. Social workers are needed for the social aspect of care.

2.1.4.3 Monitoring the spinal injury patient

As discussed above in spinal pathology, one of the major aims of treatment in spinal cord injuries is to prevent the secondary injury to the cord. The first sign that the cord injury is extending will be a change in the patient's neurological signs. It is therefore essential that regular systematic neurological examinations are performed. To aid such an examination

it is advisable to use standardised examination recording charts such as that published by the American Spinal Injuries Association (ASIA chart) (see Appendix 2).

These examinations are usually performed by the medical staff but all team members must be aware of the constant possibility of deterioration and ready to report any suspected change to the appropriate person.

2.1.5 Spinal Nerve Pathology

A radiculopathy, which is entrapment of a spinal nerve within the spine, has a much higher incidence in the general population than a spinal cord injury. The annual incidence is 1% (11). It is so common that every health care practitioner will be involved with a patient who is suffering or has suffered from “sciatica” at some stage in their career.

In the young age group (under 50 years), the most frequent cause is a prolapsed intervertebral disc. In the older population radiculopathy is usually caused by chronic disc degeneration associated with facet joint or ligamentum flavum hypertrophy leading to stenosis of the spinal canal (12).

A rare but serious complication of nerve root entrapment is Cauda Equina Syndrome. This is defined as a complex of symptoms consisting of low back pain, unilateral or bilateral sciatica, motor weakness of the lower extremities, sensory disturbances and loss of bladder and bowel function, which is a result of compression of multiple spinal nerve roots distal to the spinal cord. The incidence of this syndrome in patients with a disc prolapse is between 2 and 6% (13). The management of cauda equina is surgical decompression of the spinal canal. The timing of surgery has been debated but it is generally regarded that urgent decompressive surgery in the acute onset cases, will lead to a better outcome for the patient, as critical ischaemia progressing to irreversible neurological sequelae are prevented (13,14).

As any patient presenting with a radiculopathy can progress to a full cauda equina syndrome, it is imperative that the health care practitioners observe for the changing symptoms and signs in the individual. Once these changes are detected the appropriate investigations performed and treatment decisions must be made, in order to prevent permanent neurological damage.

2.2 Pressures within the NHS

2.2.1 The lack of specialist injury centres

As described above, a patient with a spinal cord injury is ideally managed in a specialist spinal injuries unit, of which there are eleven in the NHS. On admission to one of these centres a patient can expect to remain an inpatient for a number of months as they begin the slow road to recovery. The severity of the injury i.e. paraplegia compared to tetraplegia, the amount of close family or social support and the patients own motivation are just some of the factors determining the length of stay.

The NHS does not have the funding to allow a large surplus reservoir of resources, especially bed numbers, and so it is not unusual for every place in a specialist unit to be occupied at a specific time. One unit covering the south west of England has 57 beds and a population catchment of 11 million people. This unfortunately means that often a patient with an acute spinal cord injury cannot be directly admitted to a specialist unit and therefore is admitted instead to the local orthopaedic centre. Despite the best efforts of the staff in these orthopaedic units, it has been shown in an audit of delayed admissions to a spinal cord injury centre that approximately 40% of patients have avoidable complications (4). Pressure sores were the most frequent of these complications and the subsequent treatment of these delayed the rehabilitation of up to 12 weeks on admission to the centre. This in turn will further increase the lack of available space for new patients, meaning more patients have to be admitted to orthopaedic units instead. The problem therefore becomes self perpetuating.

2.2.2 Difficulties with the team approach

The complex management of a spinal injury involves a multidisciplinary team approach. Doctors, nurses and the numerous therapists all have important roles. In the ideal situation where a patient is admitted to a spinal injuries unit, it would be expected for all staff to have the expert knowledge and training required for the optimal management of the patient. The complication rates will be lower and the patient's rehabilitation shorter.

Unfortunately patients are not always admitted directly to these specialist units. This is often because of the lack of available beds as described above. Deficiencies within the NHS are not the only reason for delayed admission to spinal units. The aetiology of the injury is usually due to high energy trauma such as a road traffic accident and therefore

the injury to the spinal cord may not be an isolated injury. The other injuries will need to be managed in a hospital with adequate facilities, such as an intensive care unit, before transfer to the spinal centre. Therefore patients will find themselves initially under the care of the local hospital's orthopaedic department.

The experience and facilities in each orthopaedic department will vary greatly. There may be an orthopaedic consultant with a specific interest in spinal surgery among the staff but not all orthopaedic departments will have one.

The junior medical staff, including specialist registrars, senior house officers and foundation doctors, will be of varying experience and because injuries to the spinal cord are not common they may never have cared for patients with these injuries before. The risk of missing serious and potentially avoidable complications will be increased with inexperienced staff. This is the same for the all the other members of the team, who again on a standard orthopaedic ward will have a wide range of experience.

Staff shortages also place a strain on the NHS with regards to the team approach for the management of spinal injuries. It is widely documented in the popular press that there is a lack of nurses available to fully staff the hospital wards. The short fall is often made up of

agency staff (15), which are not only expensive to employ but may never have worked on the unit before and may lack the experience to look after spinal injury patients. The NHS demand for physiotherapists continues to increase but the financial constraints on NHS trusts also limits the numbers of posts available. In 2005 it was reported by the Chartered Society of Physiotherapy that 53% of newly qualified physiotherapists were unable to find posts in the NHS. In 2007 this figure was nearer 90% (16, 17).

2.2.3 Working time directive

The European Working Time Directive (EWTD) came into force for Consultants and hospital career grade doctors in October 1998. In May 2000 an agreement between the European Parliament and Council of Ministers was reached for junior doctors in training to be included in the directive (18). The agreed timetable is as follows:-

Table 1 Timetable for Implementation of the EWTD for Junior Doctors

Timetable

Date	Deadline
June 2000	Timetable set to incorporate juniors into Directive
August 2004	Interim 58 hour maximum working week. Rest and break requirements become law
August 2007	Interim 56 hour maximum working week
August 2009	Deadline for 48 hour maximum working week. This may be extended by another interim of 3 years at 52 hours if exceptional circumstances apply

The aim of the EWTD is to protect the health and safety of workers by restricting the number of hours that an individual can work and imposing minimum rest requirements on all workers (19). Junior doctors were renowned for working excessive long hours, often 72 – 100 hours in one shift, without adequate rest. Tired doctors are not able to work to their full potential; it has been shown that the effects on sleep deprivation are similar to the effects of alcohol consumption on driving performance (18).

Implementation of the EWTD was considered important to not only protect the health of the junior doctors but to also provide a safe and high quality service for patients (20). In order to implement the changes required for junior doctors hours to comply with the EWTD, that is less hours worked and formal periods of rest during each period of duty, the NHS trusts have had to use their resources more efficiently. There are not the funds available to just employ more doctors to do the same amount of work. Doctors have found themselves having to work full or partial shift rotas instead of the classic 8 to 5 with on-calls of 24 hours.

Although working a shift system does solve the problem of conforming to the EWTD, it also raises a new set of issues. Firstly in order for a junior doctor to gain experience they have to spend time working alongside their seniors, especially the consultant, during the normal working day. It is at this time that most activity within the NHS occurs, especially elective activities such as operating lists and clinics. The on call system meant that a junior doctor covered the emergency activity for a night but still performed his/her elective work the day before and the day after. Switching to a shift system means that during the period of night shifts, usually up to seven consecutive nights, the junior doctor will miss their elective activity and thus the education that would have been gained from it. In 1 study 75% of junior doctors questioned felt that implementing a shift system

would have a negative impact on their training owing to decreased attendance to their educational activities (19).

It is also apparent that working a shift system and therefore missing elective activities will mean that training will have to be longer for doctors to gain the same level of experience before feeling confident to progress up the career ladder.

Another consequence of the EWTD is the potential for the lack of continuity of care for the patient. An important element of patient care is the doctor-patient relationship. This bond or trust is required to put the patient at ease during a difficult period in their lives such as being in hospital. This doctor-patient relationship can only build as the individuals spend time together. As well as being beneficial for the patient, this relationship is also important for the doctor because it is only by getting to know the patient's condition well that the doctor can be confident in detecting any subtle changes that may indicate a deterioration in that patient. In the shift system, the junior doctor will spend less time on duty and therefore less time with a patient. The doctor-patient relationship will therefore suffer. It is now not uncommon for a doctor to meet a patient for the first time during a night shift and have to make a decision based on changes in the patient's condition that they have been told about or reviewed from the notes, rather than seen for themselves.

Taking the patients perspective, it is stressful enough being admitted to hospital but this can only be made worse when because of a shift system, 3 or even 4 junior doctors are responsible for your care in the first 24 hours. To assess patient's opinion a small sample of 20 patients who were admitted to an orthopaedic ward with trauma were asked 2 simple questions a few days after admission (see appendix 3). The first question asked if they felt it was better to have the same junior doctor in charge of their care in the first 24 hours. Figure 1 shows that 14 out of the 20 patients felt that it was better. The second question focussed on their agreement with the importance of their relationship with the junior doctor who was looking after them. Figure 2 indicates that the majority of patients did at least agree that this relationship was important. Although only a small survey, to which no statistical analysis can be applied, it does highlight from the patient's perspective the doctor patient relationship is important.

Figure 1: Would you prefer just 1 doctor to be responsible for your care on admission to hospital?

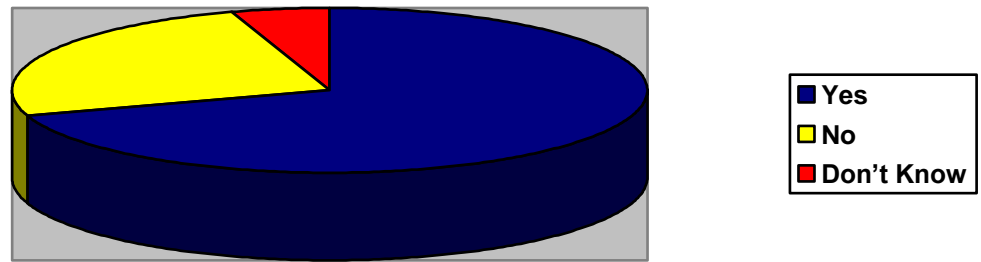
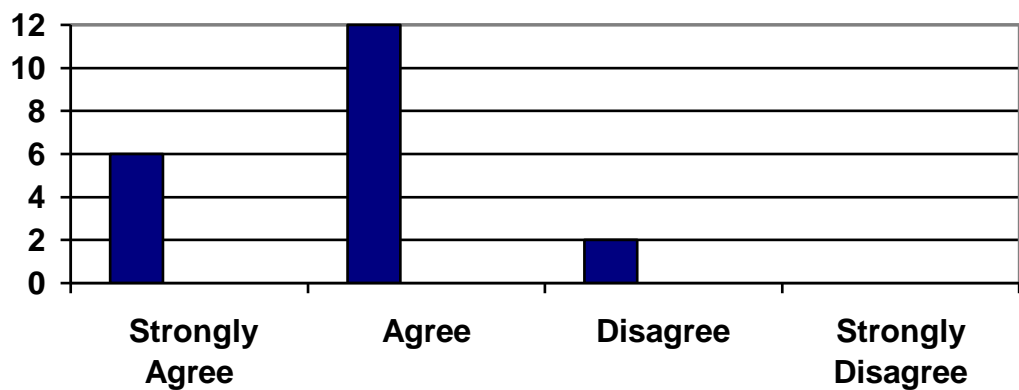


Figure 2: Do you think that the doctor patient relationship is important?



A further difficulty with the shift system is that instead of a junior doctor being on call for just the speciality that they usually work in, they find themselves covering multiple specialities at certain times. It is not unusual for the night SHO in surgery in some hospitals to now cover general surgery, urology, ENT and orthopaedics. If this doctor is inexperienced they may never have worked in the speciality that they are covering and so when a problem occurs with a specific patient, the appropriate management may not be instigated.

2.3 Standard of examination and note keeping

2.3.1 Differing Standards in examination

The neurological examination of a patient is a complex examination and an essential aspect in the assessment of a patient with a spinal injury. It involves testing several

modalities including muscle power, light touch sensation, pin prick sensation and often vibration, temperature and proprioception (joint position sense). A sound knowledge of anatomy is required because the spinal nerves that exit the spinal cord at each vertebral level supply specific muscle groups and provide the sensation to certain areas of the body. This anatomy is consistent between all individuals. A doctor should be able to ascertain the level of the spinal cord that has been affected just by the examination alone.

For assessing the power of muscle groups in spinal injury patients the MRC grading system is used in most cases (21). This is demonstrated in the table 2. Sensation to both light touch and pin prick should be tested and recorded as either normal, reduced or absent.

Table 2 – The MRC muscle power grading system

Grade	Muscle power
0	No contraction
1	Flicker of muscle
2	Movement with elimination of gravity
3	Movement against gravity
4	Movement against gravity and some resistance
5	Full Power

Teaching throughout medical school and during post-graduate training often involves learning from a number of senior colleagues at different times. Over time each individual doctor will retain certain aspects from the teachings of these seniors and discard others. In this way doctors develop their own unique clinical style. This means that when doctors perform complex tasks such as a neurological examination of a patient, the main aspects of the examination will be the same but there will be slight variations in how it is done.

In spinal injury patients, serial examinations are as important as the initial examination. Patients must be observed for worsening neurological signs, which may indicate increasing damage to the spinal cord. If worsening neurology in a patient is detected early enough, potentially reversible causes can be treated preventing a more permanent

deterioration. It is therefore important that the examination is standardised so that it is done the same way each time. This is the only way to be sure that any changes in the patient's neurology will not be missed.

Serial examinations by the same individual should in theory be performed the same way each time. Unfortunately the EWTD means that patients are now often examined by different doctors and if these doctors do have slight variations in the way that they perform the examination there will be loss of standardisation.

2.3.2 Standards of note keeping

Paper based records are the mainstay in recording patient details in medical practice. The medical record acts as an aide memoir of the patient care given and provides an essential means of communication between doctors and healthcare professionals. The record also provides a legal record of the care given.

Unfortunately the standard of record keeping is poor. It is the responsibility of the individual to ensure that their handwriting is legible to others, that inappropriate abbreviations are not used and the record includes the necessary detail. Not only is there variability in record keeping between individuals but there is also considerable variation in the record keeping practice of hospitals in England and Wales (22, 23). As stated above the neurological examination is complex and there are numerous variables that need to be recorded each time the patient is examined. If the record keeping is of an unsatisfactory standard, it is inevitable that errors will occur when patients are serially examined to observe for neurological change.

2.3.3 Surveys looking at the technique of examination and record keeping of 4 – 5 doctors asked to do a neurological examination on a patient

Two small surveys were performed to demonstrate the variability in knowledge, examination technique and record keeping of junior doctors in an orthopaedic unit.

2.3.3.1 Knowledge of normal spinal nerve anatomy

Aim

To demonstrate the variability in knowledge of junior ward doctors of normal spinal nerve anatomy

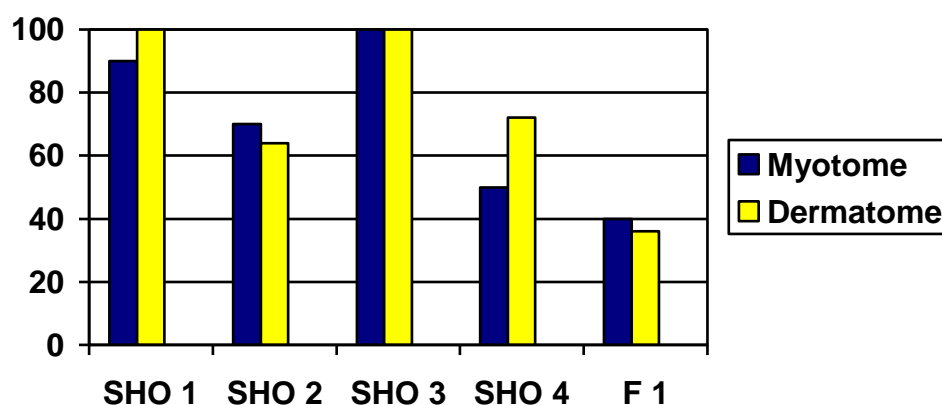
Method

5 ward doctors were asked to describe the normal anatomy with respects to the myotome (muscle groups) and dermatome (sensation supply) of the spinal nerves to both the upper limb and lower limb. Warning that they were to be tested on this topic was not given. The subjects were given a chart with the nerve roots documented (Appendix 4) and asked to fill in the muscle group and the area of sensation that should be tested.

Results

4 of the subjects were SHO's of at least 2 years experience and the fifth was a foundation doctor of 6 months experience. Figure 3 shows the results as a percentage of correct answers for the 10 myotomes and 12 dermatomes given by each doctor.

Figure 3: Anatomical knowledge of the junior doctors.



2.3.3.2 Examination technique and note keeping

Aim

To demonstrate the difference in examination neurological technique and recording of data by junior doctors

Method

5 junior doctors were asked to examine the lower limbs of a patient who was known to have a neurological deficit following surgery on a prolapsed lumbar intervertebral disc. The patient had documented weakness of extension of the left great toe (MRC grade 2/5) and some numbness over the dorsum of the foot indicating pathology of the left L5 nerve root. The patient had given consent to be examined and none of the doctors had met the

patient before. The subjects were then asked to document their findings as they would in their normal practice.

Results

The 5 subjects consisted of 1 specialist registrar, 3 SHO's of at least 2 years experience and 1 foundation doctor of six months experience.

Only 2 of the subjects (the specialist registrar and 1 of the SHO's) accurately recorded all the muscle groups and areas of sensation tested. Both of these subjects also detected the weakness of the left great toe and the loss of sensation. The specialist registrar correctly documented the weakness as grade 2; the SHO did not document a grade, just that the toe was weak.

1 SHO recorded the weakness of the toe as grade 2 and the loss of sensation but then documented the rest of the examination as muscle power and sensation normal. There was no recording of exactly what was examined.

The foundation doctor accurately recorded all of the dermatomes, including the decreased sensation over the dorsum of the left foot but failed to detect the weakness of the toe because they did not routinely examine toe extension when they performed a neurological examination. The rest of the muscle groups tested were recorded.

The final SHO just recorded the examination as NAD, short hand for no abnormality detected, for muscle power and sensation. There was no documentation of what had been examined.

2.3.3.3 Conclusions of both surveys

The number of subjects in both surveys was small; therefore no attempt has been made to attach any statistical significance to the results. The findings do seem to support the fact that there is variation in amount of knowledge that an individual doctor possesses with respect to the normal spinal nerve anatomy, even between doctors of the same rank. The variation in examination and data recording is also demonstrated. All of the subjects tested, except the specialist registrar, work a shift rota in line with the EWTD. The system worked in this NHS trust means that over a 24 hour period up to 3 different SHO's will be responsible for the care of a patient admitted as an emergency with a spinal injury. If the serial neurological examination is performed and recorded differently each time it is clear to see how a progression in the patient's neurology may be missed.

3 Technical Chapter

3.1 *Learning using Information technology*

The use of computers as an educational tool has revolutionised the way we educate ourselves. The exponential increase volume of source material available as well as the ease of access to such material via domains such as the World Wide Web means that information communication technology has become integral in medical education.

3.1.1 E-Learning

E-learning can be described as “*the process of learning which is supported by the use of ICT*” (24). E-learning is a term that encompasses a wide range of instructional material that is available on CD-ROM or DVD for stand alone computers, local area networks or on the internet.

The potential of the internet to provide web based educational tools was recognised in its infancy. Graziadei (25) in 1993, the year that the World Wide Web was declared free to all in the US, described an online computer delivered lecture, tutorial and assessment project that utilised software programs allowing the instructor and students to create a Virtual Instructional Classroom Environment in Science (VICES). Further work by the same author showed that products that were to be used for technology based learning had to be easy to use and maintain, portable, replicable, immediately affordable and cost effective (26).

An advantage that E-Learning has is that it is naturally suited to distance learning. A Virtual Learning Environment (VLE) is created which handles major aspects of a course through a user interface developed by the institution. Taken to the extreme there are physical universities and now newer on-line only colleges offering academic degrees where the programs are delivered on completely online. Distance learning is more flexible allowing the student to learn from the various information sources at their own pace without regular communication with their instructor, known as asynchronous learning, or by synchronous learning where communication with the instructor can be maintained by the use of websites and conferencing, without the need to constantly travel to and from the academic centre.

3.1.2 Goals of E-Learning

As with any method of teaching the main goal of e-learning is to provide the optimum environment for the student to retain new information or acquire new skills. For information-based content, the information needs to be presented in such a way that it can be easily digested and recalled by the student and it must be readily accessible at all times by all individuals that require it. In performance-based content, the student is expected to use the available sources to acquire new skills and with repeated use become more proficient at said skills. It should be apparent from the previous sections that in the management of a spinal injury patient, any prospective user may require the HCI to provide both information-based, i.e. what myotomes need to be examined, and procedure-based content, i.e. how to examine for each myotome. The design of the HCI is therefore fundamental in achieving these goals.

3.1.3 Blended Learning

“Blended learning is learning that is facilitated by the effective combination of different modes of delivery, models of teaching and styles of learning and is based on transparent communication amongst all parties involved with a course” (27). The ultimate aim of blended learning is to provide realistic practical opportunities for learners and teachers to make learning independent, useful, sustainable and ever growing. (28)

Blended learning increases the options for greater quality and quantity of human interaction in a learning environment and this mix of technologies and interactions results in a socially supported, constructive learning experience. (29).

The use of E-Learning modalities combined with face to face teaching between the student and instructor on the use of a HCI is a classical example of blended learning. Initially the student would be expected to require significant amounts of guidance on how to use the interface but the instructor would be able to use this guidance more sparingly as the user gains experience. (30)

Blended learning is the method usually used in the clinical setting for users to learn how to use a new computer system. An example would be a member of staff arriving at a new hospital will be given a face to face tutorial on how to use the computer results system, with run through examples and then the staff are supported in their use of the system with drop in sessions and telephone help lines.

3.1.4 M-Learning

M-Learning can be defined as “*Any sort of learning that happens when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of the learning opportunities offered by mobile technologies*” (31). This definition is broad in that it encompasses mobility when considered from both the learner’s point of view as well as the technology used. When considering the learner, M-Learning just means that formal or informal learning has occurred whilst the learner is on the move i.e. last minute revision on the way to an exam or teaching by a consultant on a hospital ward round.

Technology advances in hardware such as wireless mobile phones, PDA’s and laptops as well as improving technical and delivery support systems such as 3GP, Wi-Fi and GPRS has allowed E-Learning to step out of the classroom, library or study and given users the ability to learn when and where they desire. This convenience of access that M-Learning provides to all the differing learning materials available as well as the fact it can be regarded as collaborative, in that sharing of data between users is almost instantaneous leading to rapid feedback and tips, makes learning in this environment a more effective and entertaining experience. (32)

3.2 Use of information technology in clinical practice

3.2.1 As an educational tool

Medicine, by its evolving nature, is a career in which the individual can never stop learning. Breakthrough advances in all fields of medicine are regularly occurring throughout the world, new evidence becomes available either supporting or rejecting current treatments or methods of management. A physician or surgeon needs to keep abreast of these advances in order to practice up to date evidence based medicine, thus providing the best care for his/her patient population.

Historically this would mean long hours in libraries and educational facilities reading the latest paper based medical journals and text books. There would also have been large numbers of air miles collected having to attend conferences and courses throughout the world.

E-Learning has revolutionised this process. At the push of a button access to entire libraries of current medical literature can be accessed without the need to spend long hours thumbing through medical texts. Software such as disc forms of textbooks can be purchased to download on to computers. Targeted searches, using the internet, on the topic being studied can be performed with ease. Databases such as *Medline*, which adds over 400, 000 new papers each year, are readily available for such searches.

Medical journals, which historically have been where advances in medicine are first presented to the population outside of the research groups, have also developed electronic editions (e-journals) of their paper based journals. This e-publishing has a number of advantages including targeted searches as mentioned above, the speed at which the information can be passed onto the population as well as allowing a faster response by the population to the research in letters of reply.

Teaching using E-Learning is beginning to be integrated alongside or replacing traditional lecture based programs in medicine. Studies, including randomised controlled trials, have shown that E-Learning is at least as effective as traditional based programs in both knowledge gained and attitudinal changes of the users (33, 34). E-Learning programs have been shown to be more cost effective and allow for more independent learning through materials that can be easily updated (33). These benefits gained from an E-Learning program appear to be independent of age of user, group size and previous technology experience (35,36). The advantage of E-Learning are such that the UK Department of Health has made medical E-Learning a priority, issuing guidelines for NHS staff to select and implement a virtual learning environment, aiming to establish common approaches to learning across the health sector, thereby enhancing the knowledge and potentials of learning delivery and support systems (37). By embracing E-Learning, the Department of Health has now become the largest E-Learning provider in Europe (38).

3.2.2 As a research tool

The computer is basically a machine that allows the collection, manipulation and storage of a large amount of data extremely quickly. This makes the computer an invaluable tool

in medical research where large quantities of raw data are often required in order to provide statistical significance to any results.

Medical trials are often multi-centred and the use of networked computers has revolutionised the collection of data in these trials. Researchers at the different institutions involved in the trials can use the networks to access, add and analyse the collated data without delay. An example of such network system would be the Collaborative Orthopaedics Research Environment (CORE) project (39). This JISC funded project which built on the work carried out under the Virtual Orthopaedic European University (VOEU) project (40) provides a coupled infrastructure that combines clinical, educational and research in one working environment. One of the functions of CORE was to provide the registered users a secure network site where a project proforma can be constructed and results collated for multi-centred clinical trials without the researchers have to meet to pass on information.

3.2.3 As a tool in the clinical setting

The use of a computer as a tool in the office, for education and for research has already become widespread in modern medicine. It would be difficult to argue that the benefit that a computer brings to all of the above situations is not huge. Implementation of information technology in the clinical setting, where the system will have a direct impact on patient care and potential safety, has taken longer to gain widespread acceptance. With improvements in both hardware and software, these new digital based system are beginning to supersede the old systems.

3.2.3.1 Radiology systems

A good example of this progression is the switch by clinical units to the use of digital imaging systems in radiology. With the traditional “hard copy” system of x-ray presentation there were a number of problems which included the loss of patient’s images, long turn around times for the clinician to get copies of reports from the radiologists on the more complex investigations and lack of storage facilities for the vast amounts of x-ray films that a large unit would produce over the years (41). The use of a digital system, where all images are stored electronically, can be viewed from any suitable work station within the unit and reports can also be instantly accessed was seen

as the solution. The installation of these Picture archiving and communication systems (PACS) began in larger numbers in the late 1990's (42).

Early concerns were raised regarding the ability of PACS to provide images of sufficient quality to allow the clinician to make accurate diagnoses. These concerns have been addressed with developments in both the hardware and software and subsequent studies showing that PACS images are at least comparable with hard copy images in various fields of medicine, including chest imaging (43), scaphoid fractures (44), in the general accident and emergency department (45) and paediatric emergency imaging (46).

User assessment of PACS, regarding issues such as facilities available, quality of images, accessibility of reports and images, training and ease of use has been assessed (41, 42, 47, 48). User response is generally favourable with 85 – 97% stating that such systems benefited their work and therefore they would recommend the system to others. Issues raised in these studies concentrate mainly on potential downtime of the system with lack of access during these periods, indicating the need for sufficient short term storage to provide an efficient back-system(47) and the lack of training that some users had received prior to using the system, up to 50% in one study (48).

This user concern regarding lack of training shows the importance of the approach taken to educate the user when introducing new technology. As discussed above E-Learning is a powerful educational tool but in certain situations it is best used as part of a blended learning process. If during the implementation of PACS the opportunity for face to face tutorials had been available to all users then even higher satisfaction scores may have been achieved.

3.2.3.2 Computer assisted surgery

Computer assisted surgery (CAS) is another example of how information technology is being incorporated into clinical practice. This is a massive field of development in all surgical specialities but concentrating on the authors specialist field of orthopaedics, CAS has already been shown to improve implant alignment in total knee replacement (49,50), total shoulder replacement (51) and total hip replacement (52,53,54). Eventually development will become so advanced that computer led surgery may become viable, removing the chance of human error from the surgical procedure.

3.2.3.3 Telemedicine

Defined as “*the ability to provide interactive healthcare utilizing modern technology and telecommunications*” (55), telemedicine is further evidence of how information technology has improved healthcare. It enables patients to have real-time (synchronous) consultations with medical practitioners over video links or videos/stills can be stored and sent for later diagnosis, known as the store and forward concept (asynchronous). This has been especially beneficial for patients or small clinical units in remote areas of the world or for gathering second/ third opinions of rarer conditions by world wide experts.

Observing a patient’s condition post surgical/medical procedure at home instead of in hospital is another role for telemedicine. Known as Home Health Telemedicine, this method of remote observation not only allows patients to be treated in their home environment which can be beneficial both physically and psychologically but saves valuable hospital resources such as bed spaces and staff hours.

3.2.3.4 Electronic health records

Information technology is yet to surpass the pen and paper in this aspect of clinical care. Most hospital units still record the day to day observations and management of the patient using paper notes, clinic letters still are sent as a hard paper copy to the patient’s general practitioner and referrals to specialists arrive via the post. Each patient registered with a hospital will still have a folder of notes (in some cases several volumes thick), these notes will often be the only record of the patients previous medical problems and care. This system is far from perfect with notes and referrals often going missing, patient folders falling apart due to excessive handling and lack of storage facilities for such a large amount of documentation. It is apparent from the offset that a computer based system would solve the above problems. By recording the documentation on to computers the need for a large amount of storage space is removed. The loss of a set of notes, either by being misplaced or physically damaged, can no longer occur. Also with a network of computers multiple physicians in different specialities and centres, will be able to view the notes of the same patient at the same time, removing the need to physically transport the folders from clinic to clinic.

Using the International Organisation for Standardisation definition (56) Electronic Health Records (EHR) describes a repository of patient data in digital form, stored and

exchanged securely, and accessible by multiple users. A number of different types of EHR have been introduced and undergone preliminary assessment in both the hospital and general practice setting (57), including electronic interviews concerning their medical history, computerised diaries that allowed patients to control their medications or record activities such as food intake and urinary voiding, and full computer-based patient record systems (CPRS) for nursing and medical staff.

CPRS's have been shown to have the potential to improve the quality and reduce the cost of health care (58). CPRS's can be considered "cognitive artefacts", which shape the way in which healthcare workers obtain, organize and reason with knowledge. Paper based records have a more narrative and less organised structure compared to the CPRS, often being just a blank sheet of history paper, allowing for more variation in what can be and is documented. The more formal structure of a CPRS acts as a guide for the doctor, making it conducive to more complete documentation by the healthcare professional (56,59). Exposure to CPRS's not only affects the way a doctor collects the data but also influences how this data is interpreted and acted upon.

Recommendations regarding management protocols can be built in to these computerised systems and have been shown to improve clinician compliance with practice guidelines for patient care (60) but it must be kept in mind that any decision made on inaccurate data will be invalid (56). This means that any system design must concentrate on the accuracy of data collection before implementing management policy on that data.

3.3 *Hardware availability in the NHS*

The incorporation of information technology into clinical practice is not only dependent on the design of new software but is also reliant on the hardware available for the user to interface with. Due to financial constraints within the NHS, only certain types of hardware may be present in the clinical areas.

3.3.1 PC desk top

All hospital wards have at least one desk top PC. These are used for routine functions that are required for the day to day running of the ward. The ward clerk will have access in order to trace notes, request outpatient appointments, trace patients etc. By using the

hospital intranet, other staff, such as doctors and nurses, has access to hospital policies and blood results (via the pathology systems). Due to the lack of numbers of individual machines and number of staff wishing to use it, it is often quite competitive to gain access to for periods longer than a few minutes. These computers are therefore only useful for short functions, i.e. getting that one blood result.

3.3.2 High definition screens

With the development of digital radiology there has been a requirement for PC's with high definition screens, so that the digital image can be viewed to a standard that will allow appropriate interpretation of the image. This has led to an increase in the number of workstations with high definition screens available on the standard ward.

3.3.3 Bed side computers

There are some units that have begun to install computers at each patient's bedside (61). This has the advantage that there is no computer sharing between staff and a patient's details can be instantly accessed via their bedside computer. Within the NHS, bed side computers are mainly limited to small units, such as intensive care, rather than the standard thirty bed ward because of cost and space availability.

3.3.4 Mobile Devices

Handheld computers such as Personal Digital Assistant's (PDA's) are beginning to be employed in healthcare practice and their level of use is expected to increase (62). They are convenient to use in clinical situations for quick data management, with the capacity to allow the clinician to access, analyse and update patient's medical records from anywhere and at any time (63). Any data on the PDA can be easily synchronised with standard PC's (64) as well as allowing exchange of information between individual clinicians on ward rounds and handovers at the end of shifts (65, 66).

A literature review entitled "*The Use of the Personal Digital Assistant Among Personnel and Students in Health Care*" by Lindquist et al (62) analysed 48 articles published between 1999 and 2008. This revealed that the use of PDA's in healthcare setting might improve decision-making, reduce the numbers of medical errors and enhance learning for both students and professionals. It must be noted that the authors did admit that this evidence was not strong, with the majority of studies being descriptive only and that there was a need for further intervention studies including randomised controlled trials.

Barriers have been identified regarding the use of mobile technology in healthcare. These include technology restraints such as battery life and small memory capacity, usability and wireless networking (67, 68). Technology restraints, such as battery life and small memory capacity, should be easily overcome by constantly expanding technology (62). Usability is an issue that must be addressed with all new technologies, not just specific to mobile devices, and is discussed in much further detail in subsequent chapters and therefore will not be discussed further here.

Wireless networking, needs to be considered because of three important issues that can arise, these being data confidentiality, security of any NHS wired network and interference with medical equipment. An example of how, by close liaison with relevant NHS committees, these wireless network issues can be resolved is described by Turner et al (68). By using IPsec, which is an open standard for securing network travel in IP networks, adequate levels of security and confidentiality were achieved. Thorough interference testing by Medical Physics of the chosen mobile devices with all relevant sensitive medical equipment that may be encountered ensured that said mobile devices were safe to use.

3.4 Summary

In the hospital setting, where the pressures of the EWTD has meant a loss in the continuity of care between a doctor and patient and the experience of the doctor in that speciality cannot be guaranteed, the work in this chapter would suggest that the development of a CPRS combined with a blended learning approach, involving e-learning and face to face tuition, will standardise the initial and subsequent assessments of a spinal injury patient's condition, as well as improve clinician compliance to management protocols.

The design and user evaluation of a HCI for repeat serial neurological examination in spinal injury patients, which form the basis of this project, will aim to begin to validate this hypothesis.

4 Design Chapter

4.1 Objective of research

It will have become apparent from the above background research that the optimum management of a patient with a spinal injury is dependent on a multitude of factors. These factors include the type of unit that the patient gets admitted to and the experience and make up of the team that look after the patient following the injury. Appendix 5 describes some possible scenarios that may occur. Scenario 1, which is the ideal, is what would happen to a patient admitted to a spinal injuries unit with an adequate number of appropriately trained staff and proper continuity of care. It would be expected that this patient would have the greatest chance of the best possible recovery. Unfortunately due to a number of factors, discussed above, this is not always possible in the NHS. The second scenario describes the situation which needs to be avoided because this results in the highest probability of poor outcome for the patient. It is the aim of the research project to attempt to convert this poor prognosis scenario into the situation demonstrated in scenario 3, where the designed interface helps the team detect and manage a neurological deterioration in a spinal injury patient appropriately, even with the lack of optimum resources.

4.2 Objectives Statement

To design and test the usability of a prototype Human Computer Interface (HCI) for documenting repeated neurological examination of patients with spinal cord injury, spinal column fractures or compression of spinal nerves

- To standardise the examination and method of recording the data
- To bridge the gap of knowledge between the differing experiences and skill levels within the multidisciplinary team with respect to the neurological examination
- To increase the detection rates of patients neurological deterioration and therefore improve the standard of care

4.2.1 How the HCI is expected to affect the target persona's

4.2.1.1 Persona 1 – The consultant

With the consultant being the most senior member of the medical team, they are the health care professional who is overall responsible for the care of the patient and so if there was to be an adverse event, it is the consultant who has to face any criticism (just or unjust) and deal with the repercussions.

It is not expected that this system will be of benefit from an educational point of view, one would expect a consultant to have the knowledge and skills to perform the required examination. Where this HCI will be of benefit is that it will provide the consultant with the reassurance that the patient who is under his/her care, has been properly examined by more junior members of the medical staff and the findings appropriately recorded. Also if serial examinations performed by different junior doctors are required, they will be performed to the same standard.

4.2.1.2 Persona 3 – The junior doctor

It is this group of medical staff that the HCI will benefit most. Section 2.3.3 showed that the knowledge on how to examine the neurological system between junior doctors did vary between individuals. The methods of recording the results of the neurological examinations also varied considerably. This is potentially a serious clinical and legal problem if an adverse event were to occur.

For the more inexperienced junior doctor it is hoped that the HCI will help fill refresh them in the finer points of the neurological examination when they use it for the first few times. As their skills increase, they will use the system as less of an educational aid and more as a template for recording their findings.

The junior doctors working shifts will also benefit when asked to perform a serial examination on a patient who they may be meeting for the first time. By standardising the examination records, any doubt of whether a patient's symptoms have changed should be removed.

4.2.1.3 Persona 2 – The SpR

The experience of the SpR falls between that of the consultant and the more junior doctors. Again the SpR should be experienced enough not to require the system as an educational device but more as an aid memoir for the examination, especially if they are a more junior SpR. The main benefit for the SpR will again be in the accuracy of previous examination documentation when called to perform a serial examination on a patient who is thought to have deteriorated clinically.

4.2.1.4 The rest of the multi-disciplinary team

Other members of the team such as nurses and physiotherapists are generally not expected to perform the neurological examination routinely. Firstly the HCI will provide these team members with an educational tool to improve their own medical knowledge but more importantly will aid them in making a clinical decision about whether to involve the medical team urgently. It can be a difficult decision for these staff to call a doctor to examine a patient urgently, especially in the middle of the night. If by consulting the HCI it makes this decision easier for the staff member, the system will have been of benefit for the individual and patient involved.

4.3 The basis of HCI design

4.3.1 Interaction design

Interaction design is defined as “designing interactive products to support people in their everyday and working lives” (69). The principle of interaction design encompasses all aspects of researching and designing computer based systems for people. These include:

- Design practices : e.g. *graphic design, artist design, product design*
- Academic Disciplines : e.g. *ergonomics, software engineering, informatics*
- Interdisciplinary fields : e.g. *human computer interaction, cognitive engineering/ergonomics*

Human computer interaction is “concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them.” (69) It is this aspect of interaction design which is relevant for this project.

4.3.2 The process of interaction design

The process of interaction design involves four basic activities (69):

- 1) Identifying the needs and establishing requirements
- 2) Developing designs that meet those requirements
- 3) Building interactive versions of the designs
- 4) Evaluation throughout the process

In order to complete a design project all of these activities must be addressed. It is also essential to understand that the process is a feedback system, with each activity affecting those that precede as well as succeed it. The activities will often require repeating in order to achieve the project goals.

4.3.3 The use of prototypes in interaction design

Prototyping is not a new idea. It was first used as a tool in developing hardware (70) but now the use of prototypes has become a key component in achieving the process of interaction design.

4.3.3.1 What is a prototype?

A prototype represents a simplified model of a final design and its function is to allow the designers to make changes to the design before the final development is too advanced.

Prototypes serve a variety of purposes including (69):-

- testing out the technical feasibility of an idea
- to clarify some vague requirements
- to do some user testing and evaluation
- to check that a certain design direction is compatible with the development of the rest of the system

4.3.3.2 Types of prototype

A prototype can take many forms. One way of classifying them is as follows:-

1) Static Prototypes

These types of software prototypes tend to be paper-based. A series of sketches or screen images are designed which can then be put together to form a storyboard. This storyboard

will demonstrate how a user might complete a given task using the device that is being developed.

The advantages of such prototypes are that they are simple, cheap and quick to produce. This also means that the modification of these prototypes is also simple, cheap and quick. This is especially important in the early stages of interaction design because the initial exploration of design ideas should be flexible to allow alternative solutions to be considered.

2) Interactive Prototypes

These prototypes use materials that one would expect to find in the final product and therefore tend to resemble the final product much more than a static prototype does. An interactive prototype of a software system will demonstrate the functional aspects of the final design to the user better than a static prototype would. This allows the user to gain a better understanding of how the final product will eventually look and feel and therefore the user can give a more informed opinion when being asked to evaluate the system.

4.3.3.3 Pitfalls in prototype use

Both types of prototype described above have potential pitfalls which must be taken into consideration by developers when designing a system.

A static prototype, as inferred to above, does not resemble the final design closely. Its use is restricted to establishing the requirement of a design and has no use with respects to usability testing. It has been shown that when a design has major usability problems evaluators using an interactive prototype were significantly more likely to identify the problems compared to a group using a static prototype (71).

Interactive prototypes are more expensive and time consuming to create compared to a static system. If used too early in the design process, the development team may find an interactive prototype will limit the number of alternative solutions that are explored before deciding on a final design.

There is also a danger in developing an interactive prototype that the design team will want it to mimic the complete user interface, making the prototype become a product of its own. By creating such a complex prototype, any issues raised during testing with

respect to the usability become much more difficult to correct, requiring a large amount of time, man power and potential expense to perform the adjustments.

4.3.3.4 How to use the different types of prototype

From the above it can be concluded that the different types of prototype can be used in conjunction to complete the four basic activities involved with interaction design described above in section 4.3.2. At the beginning of development, a static prototype should be used to help establish the user requirements. The ease of modification of these prototypes allows for all possible solutions to be explored before committing to a design pathway.

Once the user requirements are established, an interactive prototype can be developed so that more detailed usability testing can be performed. In order to achieve a final product, following evaluation, the interactive prototype can then be used in one of two ways. (69) With *evolutionary prototyping*, the prototype evolves into the final product, having new aspects built onto the existing prototype or changes made to other components. Throughout this process the prototype must undergo extensive testing with each change. The other method, *throwaway prototyping*, uses the prototype as stepping stones towards the final design. The prototypes do not make up part of the final design but instead the finished product is built from scratch.

4.4 The steps taken in the HCI design

The following section describes method used to develop the HCI. The basic activities for interaction design described above were used as the model

4.4.1 Identifying user needs and establishing requirements

Before considering the design of this HCI, it was important to establish the role of the target users within the multi-disciplinary team and how this HCI could benefit them. The advantage that author has with respects to this activity is that his background is in medicine and not interaction design. The author has been a junior doctor and is currently a SpR in orthopaedics and so has direct experience of 2 of the main target personas.

On commencing the project the author had informal discussions with consultants in orthopaedics and nursing staff on the orthopaedic wards. The aim of the discussion was

to gain insight into the target personas that the author did not have direct experience of. Following these discussions the author was able to draw some broad conclusions about how the HCI would affect each persona group described in section 4.2.1

4.4.1.1 One to one interviews with junior doctors

It is expected that the group of users who will be using the HCI the most are the junior doctors. It is also expected that the system once designed will be of most benefit to this group as an educational tool. It was felt that questioning about possible requirements should be conducted in more detail with this group. Section 2.3.3 describes the results of a small survey of junior doctors regarding standard of examination and recording of the examination findings. Once the subject had completed their participation in the survey, the author conducted a one to one interview regarding the planned project to gain a further insight on possible user requirements. The main points that arose are discussed below:

1) Time constraints

The most common issue that arose was the concern that having to use a HCI to fill in the details of the examination would be too time consuming, adding to an already busy working day for the junior doctor. Any designed HCI would therefore have to be quickly accessible and straightforward, to use so that inputting the data would take approximately the same length of time as writing the examination out on a piece of paper.

2) Information given by the system must be balanced against the user's knowledge

One potential difficulty that became apparent, was how much factual information regarding performing the examination, should the HCI present to the user. There will be a varying degree of experience between users. A recently qualified foundation doctor may initially require a significant amount of guidance to complete the examination and so to present too little information will mean that the HCI will be of minimal help. On the other hand by presenting too much factual information on the system, a more experienced user may find that this slows down his/her ability to input data; as discussed above time constraints was one major issue that was raised. "Professional pride" is also an aspect that was raised. A more experienced doctor may consider the HCI as an insult to their clinical ability, if the system tries to "spoon feed" how to perform the examination.

It is apparent that the system, when designed, needs to present itself as a method of recording accurate serial examinations to the experienced user but also provide more factual details about how to perform the examination to the less experienced.

3) Serial examinations and the shift system

One aspect of the proposed project that certainly met with a positive response was the ability to standardise the examination findings for serial examinations by differing doctors. Comments about being unable to read other doctors handwriting and paucity of documentation by colleagues combined with concerns over the lost of continuity of care due to shift based work patterns would seem to indicate that this aspect of the system is a major selling point.

4) The hardware

The last major issue that was raised by the subjects was what type of machine would be used to record the data. The hospitals at which the subjects were questioned have not implemented any form of digital note taking either by bed side PC or mobile device. A couple of subjects did raise questions about the relevance of designing a software system without having adequate access to appropriate machines to work with.

4.4.1.2 Previous work on acceptance of CPRS

The HCI will use a CPRS to guide the recording of the examination. Although the benefits of CPRS are apparent, the acceptance of these systems by clinicians has been slow. The structured nature of a CPRS, which is one of the major strengths of such a system, must also be considered one of its weaknesses. The use of such a structured system will be more time consuming than a paper based process, where a clinician will use their own clinical experience to tailor the data collection and thus save time. In the analysis of CPRS it has been shown that there are key items that must be considered in order to reduce the time taken by the clinician to use the system (59):-

- 1) The screen design must allow the information to be displayed in such a way that it enables the clinician to focus on the key data and thus make appropriate decisions.
- 2) The terms used must be those familiar to the clinician and not the designers/programmers

3) Routine tasks such as entering the data must be straight forward

If these key items combined with the issues raised during the one to one interviews with the junior doctors can be addressed when designing such a system, there will be a higher chance of obtaining widespread acceptance and ultimately use in the clinical setting of the system.

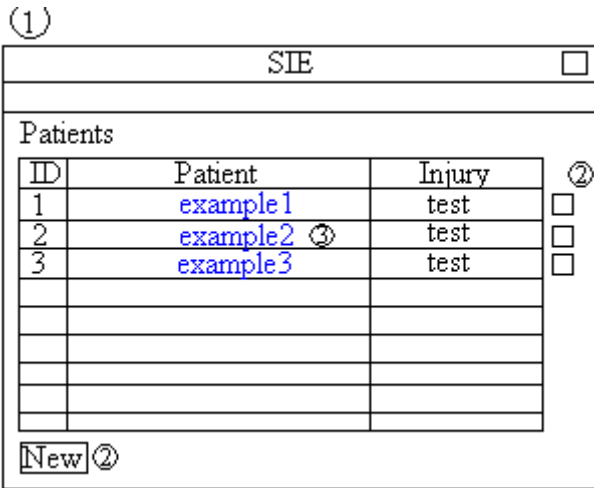
4.4.2 Developing a design that meets with the user requirements

Once the user requirements had been established the next stage in the design process was to begin development of the HCI. A static prototype, in the form of storyboards, was used to map out what would be displayed to the user on each screen and how the user would progress through the system.

The development team consisting of the author, acting as a user, a computer programmer who would be responsible for the coding of any interactive prototype and a senior supervisor then met to evaluate the static prototype. Adjustments to the prototype could easily be made (an advantage of the static system as described above). This predictive modelling, see section 5.2.1, resulted in the following static prototype.

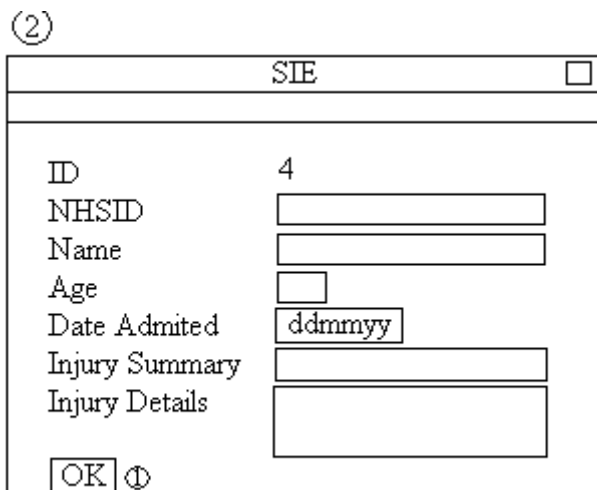
4.4.2.1 Screen 1- The patient identification page

The opening page that would greet the user when accessing the system shows patients who have been examined previously and therefore have data stored in the system. The patient's names are linked to beginning a new examination on that patient. A "New" button at the bottom of the page allows for a new patient to be examined to the system. Edit buttons at the right of the screen will allow the user to edit the patient's details.



4.4.2.2 Screen 2 – New patient details

The user is to be directed to this second page if they wish to add a new patient or edit details on a patient that is already on the system. For the New patient the user can input all of the standard patient details that are required for any documentation including name, hospital I.D. number, date of birth, date of admission etc. A “potted history” of the injury that the patient sustained can also inputted on this page. Finishing the creation process adds the patient to the data base an returns the user to the initial page. When editing the patients details this same second page is brought up but with the existing values already entered.



4.4.2.3 Screen 3 – Assessment information page

This assessment page is displayed when the user has indicated that new examination is about to be performed by clicking on the patients name on the initial page. The page is split into 2. On the right is an image of a body, although the user cannot interact with this at first. Information data about the patient is displayed above the image. On the left the user is prompted for information about the assessment that is being performed, such as the examiners name and location of the assessment. The date and time is defaulted to current but can be changed if required. Clicking “ok” will activate the body image and begins the assessment.

③

SIE	
Assessment Info	ID: Name: Age:
Examiner Name	Injury:
Date	
Time	
Location	
④ OK	

4.4.2.4 Screen 4 – Recording of results page

On this assessment page the right hand pane remains static. The left pane is used to display the questions. Various limbs and body parts are encapsulated with a coloured box. Initially these will all be red. Red signifies that no data has been entered on the part, yellow shows that some data has been entered and green indicates that the data in this field is complete. On clicking a body part the coloured border of the box will thicken and the appropriate clinical questions will appear on the left pane. Radio buttons are used to record the score for each piece of data. The guide button allows more factual information about how the examination should be done for the more inexperienced user. When ready the user can submit the data to go to the results page.

④

SIE

R Arm C1 Guide ○○●○○○ C2 Guide ○●○○○○ C3 Guide ○○○●○○ C4 Guide ○○○○○○ C5 Guide ○○○○○○ D1 Guide ○○○●○○ D2 Guide ○○○●○○	ID: Name: Age: Injury: <div style="text-align: center; margin-top: 20px;"> </div> <div style="text-align: right; margin-top: 10px;"> <input type="button" value="Submit"/> </div>
---	---

4.4.2.5 Screen 5 – Final results page

The results page is split into two sections. The top section reveals status of the assessment; highlighting any parts of the assessment that are incomplete. In the lower half of the screen, changes with the previous assessment are displayed. Areas with an improved score are listed on the left in green and those with a worsening score are shown in red on the right. Finally the user is given the option to go back and complete any missing aspects of the examination or accept the results and return to the initial page; these results are then stored.

⑤

SIE

Assesments
R Arm: Incomplete R Leg: Incomplete
L Arm: Complete L Leg: Empty

Improvement	Decline																														
<table style="width: 100%; border-collapse: collapse; border: 1px solid black;"> <thead> <tr style="background-color: #e0ffe0;"> <th style="padding: 2px;">area</th> <th style="padding: 2px;">prev</th> <th style="padding: 2px;">new</th> </tr> </thead> <tbody> <tr style="background-color: #e0ffe0;"> <td style="padding: 2px;">T1</td> <td style="padding: 2px;">3</td> <td style="padding: 2px;">5</td> </tr> <tr style="background-color: #e0ffe0;"> <td style="padding: 2px;">E9</td> <td style="padding: 2px;">1</td> <td style="padding: 2px;">2</td> </tr> <tr style="background-color: #e0ffe0;"> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> </tr> <tr style="background-color: #e0ffe0;"> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> </tr> </tbody> </table>	area	prev	new	T1	3	5	E9	1	2							<table style="width: 100%; border-collapse: collapse; border: 1px solid black;"> <thead> <tr style="background-color: #ffe0e0;"> <th style="padding: 2px;">area</th> <th style="padding: 2px;">prev</th> <th style="padding: 2px;">new</th> </tr> </thead> <tbody> <tr style="background-color: #ffe0e0;"> <td style="padding: 2px;">D1</td> <td style="padding: 2px;">4</td> <td style="padding: 2px;">2</td> </tr> <tr style="background-color: #ffe0e0;"> <td style="padding: 2px;">C3</td> <td style="padding: 2px;">2</td> <td style="padding: 2px;">1</td> </tr> <tr style="background-color: #ffe0e0;"> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> </tr> <tr style="background-color: #ffe0e0;"> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> <td style="padding: 2px;"> </td> </tr> </tbody> </table>	area	prev	new	D1	4	2	C3	2	1						
area	prev	new																													
T1	3	5																													
E9	1	2																													
area	prev	new																													
D1	4	2																													
C3	2	1																													

4.4.3 Building an interactive version of the design

Due to the author's background in medicine and not computer sciences, completion of the storyboards was as far as could be progressed without the aid of a programmer from the ECS department at Southampton University. **Therefore the work in this section was not performed by the author alone.**

4.4.3.1 Hardware selection

Despite the increasing development of mobile devices and their use within the NHS, the vast majority of orthopaedic units do not yet have working mobile systems. All hospital wards have at least one desk top PC. The system was therefore designed for use on a PC based system. There would be scope for redesign for a mobile based system in the future.

4.4.3.2 Security of data

The use of ward based PC's also solves the problem of security. The system will carry confidential patient data and therefore requires secured access, so that only members of staff can view the patient details. By using the hospital based PC's, the system is protected by the logon passwords already in place for access to any NHS terminal.

For a member of staff to access a PC on the hospital ward, they have to use a personal user name and password. There are strict rules regarding the sharing of these passwords with other individuals and the hospital keeps records of who is logged onto a PC at any one time. This level of security will prevent unauthorised access to the system by members of the public. If an individual hospital trust wishes to make the access restricted to only certain members of staff, the trust can issue separate user names and passwords for direct access to the system when already logged onto a PC. This second level of security is used for obtaining blood results, pathology results and access to the digital x-ray systems in most NHS trusts at present.

The fact that these security systems are already in place for confidential patient data there was no requirement to build a security system into our design.

4.4.3.3 Design meetings

During the design process multiple meeting between the author and the programmer allowed the design to progress from the story boards to a full working prototype system ready for evaluation involving an user population. Predictive modelling, which is

discussed in detail in the evaluation chapter, guided the discussions. The major changes that were made to the storyboard outline during the design process are discussed in the following section.

4.4.4 The interactive prototype

The changes from the storyboard design, which were made during the development of the interactive prototype, are discussed below.

4.4.4.1 Patient and examiner identification screen

In keeping with the storyboards, the first screen shown is the patient identification screen. By clicking on the patient's name, the system is opened up to allow the examination findings to be documented. To enter a new patient to the system, the user clicks on the "New" button and this will display the patient details screen (4.4.4.2)

Patients		
ID	Patient	Injury
2	Example Patient2	test
1	Example Patient	An Example Diagnosis

[New](#)

Examiners	
ID	Examiner
2	Example Examiner2
1	Example Examiner

[New](#)

As the screen shot shows, an examiners data base was added to this page. This allowed simple and faster documentation of who was performing the examination, especially if the examiner had used the system before and therefore had already added their details. A new examiner is directed to the "New" button on the page. If this button is selected, the following page opens in the system allowing the examiner to add their details. Once completed the examiner is directed back to the opening screen.

New Examiner

First Name:

Last Name:

Position:

4.4.4.2 New patient details

This screen gives the user the ability to enter new patient details. As was planned with the storyboards the user can add a potted history if so desired.

New Patient

Hospital number:

First Name:

Last Name:

DOB:

Address:

Date Of Admission:

Admission Code:

Ward:

Consultant:

Diagnosis:

Plan:

ISS:

Comments:

4.4.4.3 Assessment details

This screen remains in two halves. The left shows the basic information about the assessment, i.e. date, time and location. A drop down menu of registered examiners derived from the new examiner section of the initial screen now exists to help speed up the data inputting.

Assesment Info

Examiner:

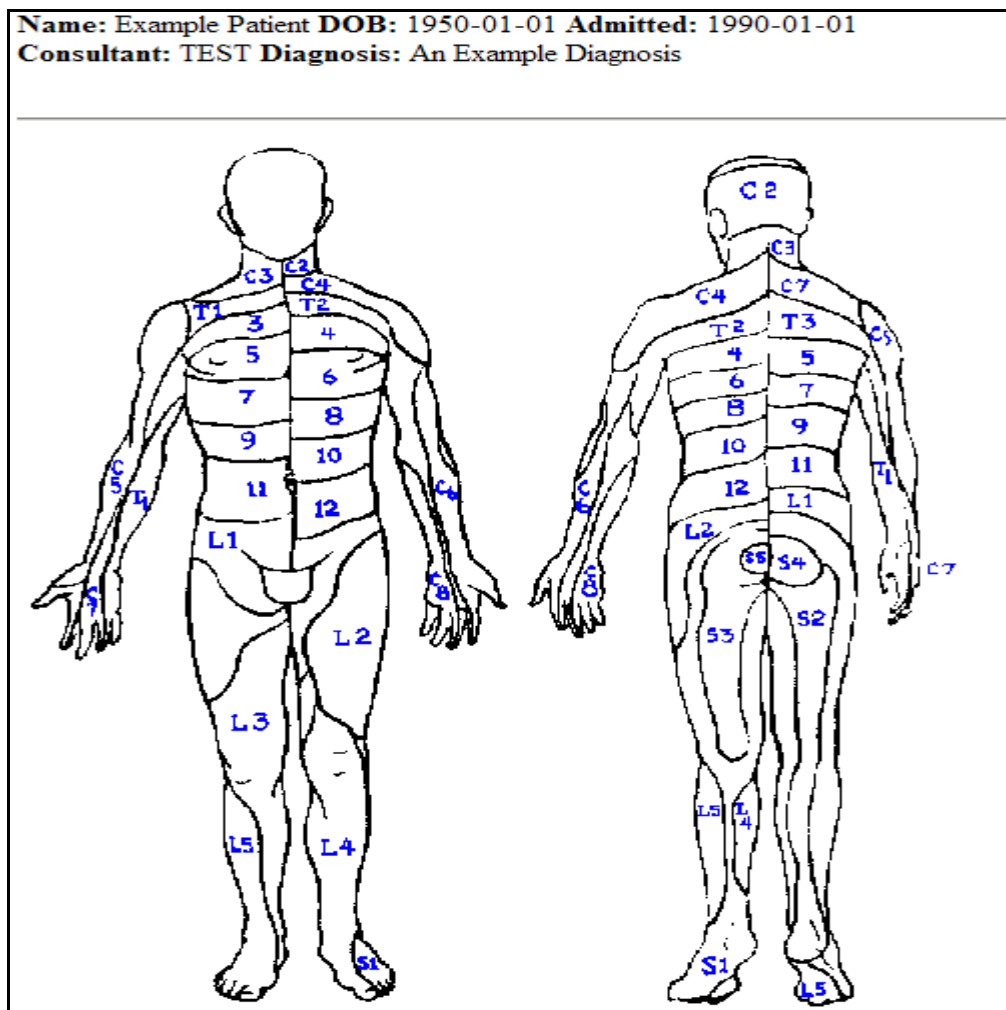
Date:

Time:

Location:

[Back](#)

The right half of the screen shows the basic details of the patient who is being examined as well as a pictorial representation of the body. As with the story board design the user cannot interact with this at present.



4.4.4.4 Recording of results page

Once this page opens the pictorial diagram of the body becomes active. The user clicks on an area of the body (left or right arms, left or right leg and trunk) and the left side of the screen then displays the results input field, shown on the screen shot below (for the left arm). The push button format allows quick input of data. Once the section is completely filled, another section of the body can be selected until the examination is complete.

Myotome Help

Left Arm

Myotomes

	0	1	2	3	4	5
C5	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
C6	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C7	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C8	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
T1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>

Reflexes

	Absent	Normal	Brisk
Biceps	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
Triceps	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supernator	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

Dermatomes

Pin-Prick

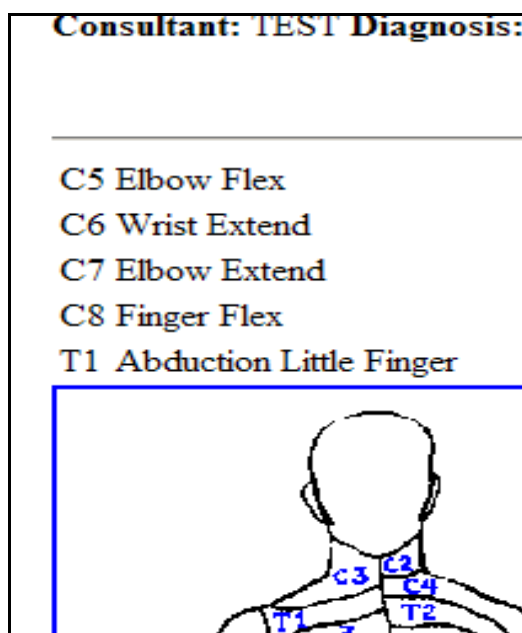
	Absent	Reduced	Normal
C5	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C6	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C7	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C8	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
T1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Light Touch

	Absent	Reduced	Normal
C5	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C6	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C7	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
C8	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
T1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

[Back](#)

To help the more junior examiner it is possible to display the myotomes that need to be examined by selecting the myotome help button. Once selected, the myotome help box appears on the left side of the screen.



Hiding this was felt appropriate because not every user needs to be reminded of the myotome supply of each limb and by doing so the screen is less “cluttered”.

It was found that the planned coloured boxing of the examination fields to show the completeness of the examination (Section 4.4.2.4), was extremely complicated to perform because areas on an image map cannot be given a border. It was felt that because this was mainly just an aesthetic aspect of the system, it would be dropped from the prototype design but could be returned to if desired by users after the evaluation.

4.4.4.5 Final results page

Once the examination is completed the user is directed to the final results screen, shown below. This displays whether the examination is complete in all fields at the top and the lower half shows any changes in the examination findings compared to the previous examination.

Assesment Status

Right Arm: Complete
Left Arm: Incomplete
Right Leg: Empty
Left Leg: Empty
Trunk: Empty

Decline		
Field	Previous Value	New Value
RArm_Myo_C5	5	3
RArm_Myo_C6	5	2
RArm_Myo_C7	5	1
RArm_Myo_C8	5	2
RArm_Myo_T1	5	3
RArm_Ref_Bicep	2	1
RArm_Ref_Super	2	1
RArm_DerPP_C5	2	1
RArm_DerPP_C6	2	1
RArm_DerPP_C7	2	0
RArm_DerPP_C8	2	1
RArm_DerLT_C6	2	1
RArm_DerLT_C7	2	0
RArm_DerLT_C8	2	1

Improvement		
Field	Previous Value	New Value
LArm_Myo_C5	0	3
LArm_Myo_C7	0	1
LArm_Myo_T1	0	4
LArm_Ref_Bicep	0	2
LArm_DerPP_C8	0	2

[OK](#)

4.4.5 Evaluation of the system

The evaluation of the system which is the fourth activity of the design process is discussed in the following chapter.

5 Evaluation chapter

5.1 Background

Evaluation has been described as “the process of examining the system or system components to determine whether or not the presence of specific properties hold” (72). Evaluating what has been built is very much at the heart of interaction design (69). It is important to ensure that a product functions as it is designed to and that it is usable in the real world.

5.1.1 Techniques of user assessments

Evaluation is usually addressed through a user – centred approach (69). There are a number of techniques that can be used for the evaluation of a HCI (73). These are described below:-

5.1.1.1 Observation

The user is observed whilst interacting with the system. Observation can be described as formal, meaning in a controlled environment or informal, where the user is observed in their natural environment. Methods of observing the users can involve:

1) Direct observation- the user is watched in real time and the assessor makes notes on the observations. This is a very flexible and unobtrusive method but relies on what the observer notices, feels is important and can record with the time that is available. The “think aloud” technique is an extension of direct observation, where the user is asked to verbally express all of their thoughts. This gives the observer more information than just observing alone as it allows the observer to know what the user is thinking. The major problem with this technique is silence. This can be overcome by the observer prompting the user to speak but this would be intrusive. A second solution is to have more than one user work together so that they talk to each other (a more natural way of working).

2) Audio/video recording- cameras etc are used to document the user interaction and body language. This can be the most complete method of data collection but can be very obtrusive (less so with more modern smaller cameras) and is very time consuming, over 100 hours of analysis can be needed for 1 hour of video recording (69).

3) Interaction logging- collecting a users actions i.e. key presses, mouse or other device movements whilst performing set tasks, using specialist software tools. This method is unobtrusive and large volumes of data can be logged automatically but powerful tools are needed to analysis the data and ethical concerns should be considered regarding the “unseen observer”.

5.1.1.2 User’s opinion

Another method, apart from observing, of establishing a user’s opinion regarding a system is to ask them. The two main techniques, interviews and questionnaires, are well established in human computer interaction (69).

1) Interviews

Interviews have been described as “a conversation with a purpose” (74). The interviewer can run the interview in an unstructured form, being like a conversation between two individuals, or make it a structured event with a predetermined set of questions to be followed. Interviews can be held on a one to one basis or involve a small group of users. Interviews are an excellent technique in establishing the user’s impressions, opinions and ideas.

2) Questionnaires

Questionnaires are a well established technique for gathering demographic data and user’s opinions. (69) The questions used in any questionnaire can be closed or open. With closed questioning the data gathered is similar to a structured interview with only specific aspects of the users opinion collected. More open questioning on a questionnaire gives the user more freedom to give their opinions, leading to a data set similar to when a semi-structured interview takes place.

One major advantage of questionnaires is that they can be distributed to a large number of users and therefore allow the collection of large amounts of data in a short time.

5.1.1.3 Experiments

The aim of an experiment is to test a hypothesis that predicts a relationship between two or more variables. Experimentation involves setting up experimental conditions that require control of all variables that could affect the hypothesis test. This will then allow

the investigator to manipulate one of the desired variables that is being tested, the so called *independent variable* and record the response to the manipulation of the second variable being tested, the *dependent variable*. Scientific experimentation, because of the amount of work that is required to set up the experimental conditions, is usually too expensive or not practical for usability evaluation (69).

5.1.1.4 Predictive models

Predictive modelling differs from the above methods of evaluation because it provides measures of user performance without testing actual users. In these evaluations, experts apply their knowledge to simulate the behaviour of less experienced users and predict the usability problems that may occur. It is a cheap and quick technique of evaluation. (75)

5.1.2 Usability Goals

The primary aim of the evaluation techniques described in section 5.1.1 is to assess to usability of the interactive product that is being designed. Usability is regarded “as ensuring that interactive products are easy to learn, effective to use and enjoyable from the user’s perspective” (69). Usability can be broken down into the following goals:

- 1) **Effectiveness** – refers to how good a system is at doing what it is supposed to do.
- 2) **Efficiency** – refers to the way a system supports users in carrying out their tasks
- 3) **Safety** – protecting the user from dangerous or undesirable situations
- 4) **Utility** – refers to the extent to which the system allows the user to do what they need or want to do
- 5) **Learnability** – how easy the system is to learn
- 6) **Memorability** – how easy it is to remember how to use a system once it has been learnt

In addition to the six usability goals above, which focus on improving productivity and efficiency, the researcher should also consider the user’s experience in using the system.

These *user experience goals* include factors such as user satisfaction and enjoyment; how helpful the user finds the system; how aesthetically pleasing the system is; the motivation that the user feels and how rewarding the system is to use.

5.2 Evaluation techniques used to evaluate the designed HCI

As described in section 5.1, there are multiple methods of evaluation that could be chosen to evaluate the designed HCI system. The evaluation process for this project used several of these methods.

5.2.1 Predictive modelling during the design process

This method of evaluation was used throughout the design process providing a feedback loop for the design programmer. At each stage of development, from the story boarding to the final prototype design, the author took the role of a more junior doctor, the persona that is the main target user, and attempted to identify the potential usability problems. As stated in the design chapter, once these potential problems were identified and discussed with the programmer, the appropriate changes were made to the HCI. Only when it was felt that the HCI had reached an appropriate standard, was the system exposed to the user population.

5.2.2 Evaluating the users

Users were recruited, taking individuals from all the persona groups that are expected to use the system. A total of fifteen users were recruited. All users were seen on a one to one basis by the author. Initially the purpose of the project was explained and then the users were given a ten minute demonstration of the system. The following methods of evaluation were then used

5.2.2.1 Direct observation on completion of tasks

The users were asked to enter the details of an imaginary patient who had supposedly been examined by them at 2 different times. The observer was quiet throughout this period but the user was encouraged to “think aloud” from the start. If the user did not express any thoughts the observer did not prompt because this would become intrusive.

5.2.2.2 Questionnaire

A questionnaire had been designed to allow detailed recording of the user's opinion. The questionnaire was designed along a standard line, with basic user demographic information being recorded followed by questions concentrating on the usability goals described in section 5.1.2. An example of the questionnaire is displayed in Appendix 6.

5.2.2.3 Interview

The final form of evaluation used was an unstructured interview. This was used in conjunction with the questionnaire to clarify and deepen the understanding of the user's opinions.

5.3 Results

The following section displays the results for the user evaluation.

5.3.1 User demographics

5.3.1.1 User selection

The user population were selected from members of the orthopaedic staff who would be expected to be involved in the care of patients with spinal injuries. The users were all based in an orthopaedic department in a large district general hospital that the author is currently working. Due junior doctors working on rotations, there is a rapid turnover of staff and therefore not all users were known personally by the lead author. Irrespective of this, to try and limit any selection bias in choosing users for the study by the lead author, potential users were divided up into their persona types (section 2.1.4.2), and then each user was randomly selected by having their name drawn. Following the draw the selected user was asked if they would be happy to participate. Of note no selected user declined.

It was decided by the lead author to have the majority of user be junior doctors, either SHO's or foundation doctors as this is the persona group who would be expected to use the interface most. Users from personas 1 and 2 (consultant and SpR's) were grouped together as members of the medical team who would use the system less frequently. One user each from persona 4 and 5 (nurses and physiotherapists) was also included so that a true multidisciplinary team opinion could be sought.

5.3.1.2 User demographics

The following table display the basic demographics of the 15 users selected.

Table 3 – User Demographics

Occupation	SR	SR	S	S	S	F2	F2	F1	F1	N	F2	F2	F1	F1	Ph
Exp in Ortho	5yr	3yr	1yr	1yr	6m	3m	n	2w	2w	5yr	3m	3m	6w	2w	1yr
Worked in spinal unit	y	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Reg neuro exams	y	y	y	y	y	y	y	y	y	n	y	y	y	y	n
Aware of any spinal scoring systems	y	y	n	n	n	n	n	n	n	n	n	y	n	n	n
Which ones	As	As										As			

SR = Specialist registrar, S = Senior house officer, F2 = second year foundation doctor, F1 = first year foundation doctor, N = orthopaedic nurse, Ph = physiotherapist, As = Asia scoring system

As stated above the majority are junior doctors (n = 11). These junior doctors have clinical orthopaedic experience ranging from 1 year to none. The 2 SpR's selected are both relatively experienced in orthopaedic with 3 years and 5 years at this level, this does not include the minimum requirement of at least 12 months as an orthopaedic SHO which is needed to become a SpR. Both the selected orthopaedic nurse and physio are also experienced with 5 years and 1 year in the orthopaedic department.

As would be expected all of the doctors regularly perform neurological examination on patients as part of their clinical practice. One of the users had worked in a specialist spinal injuries unit (the most senior SpR) and only 3 of the users had prior knowledge of any paper based spinal injury scoring systems.

5.3.2 Usability goal analysis

The questionnaire (Appendix 6) was used to collect data regarding the usability goals set out in section 5.1.2. For each goal the user was asked to comment on a number of statements about the prototype, stating whether they agreed, strongly agreed, disagreed or strongly disagreed with each statement. Each response was then given a score depending on how favourable the response was with respect to the prototype (ranging from 1 for the most negative response to 4 for the most positive). This would allow a numeric value to be given to each user's opinion. The raw data achieved by this process is shown in Appendix 7.

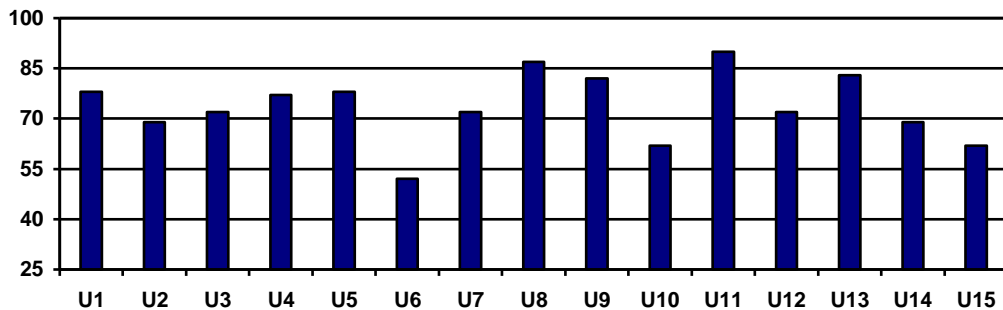
5.3.2.1 Descriptive analysis

Giving each user response to the statements for the usability goals in the questionnaire a numeric value, allows one to calculate the maximum and minimum that can be scored for each section. The midpoint in the range between the maximum and minimum values can then be termed the neutral value for that range. Any score over that neutral value can be regarded as a positive response by the user to the specific aspect of the prototype being evaluated. The converse also applies in that any score under the neutral value indicates a negative response by the user.

1) Individual user scores.

These are displayed graphically in figure 4. There is a maximum possible score of 100, a minimum of 25 and a neutral value of 62.5. The mean score for this user population is 73.6. Three user scores fall below the neutral value (two scores of 62 and one of 52), these will be discussed in section 5.4.

Figure 4 – User scores regarding usability of the prototype



2) Usability goals

The scores for each usability goal tested are shown in figure 5. For each statement the maximum and minimum values were 60 and 15 respectively. The neutral value was therefore 37.5. All but one of the statements scored higher than the neutral value. The mean values for each usability goal can then be calculated from figure 5. These means are shown in table 4. These results will be discussed further in section 5.4.

Figure 5 – Scores for each usability goal

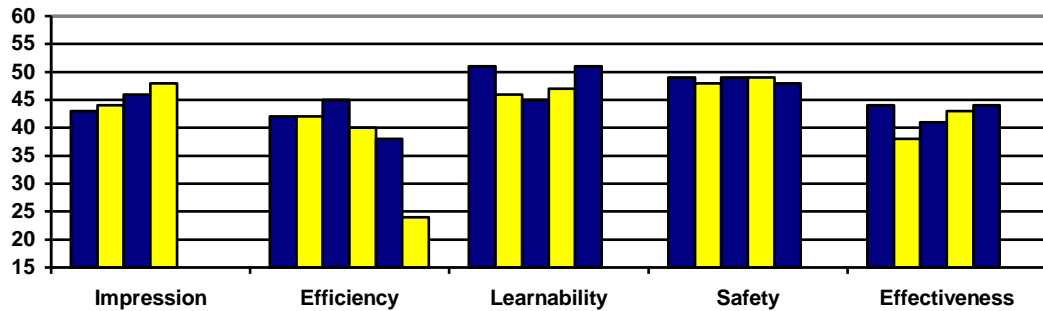


Table 4 – Mean values for usability goals

Usability Goal	Mean Value
Impression	45.25
Efficiency	38.5
Learnability	48
Safety	48.6
Effectiveness	42

5.3.2.2 Statistical analysis

The main aim of the evaluation was to test the usability of the system. Usability testing can be achieved mainly by using descriptive statistics (see section above) and qualitative data, such as user comments (see below). (70). Therefore a large amount of statistical calculation is not required in the evaluation

As will be discussed in section 5.4, the prototype appears to score positively with respects to all the usability goals, only scoring a negative result with respect to the neutral value in 1 of the 25 statements in the questionnaire. In order to test the significance of this result some inferential statistics were needed. The user responses to the statements for each usability goal were compared to the neutral value using a student t-test. Our Null Hypotheses is that there is no difference between the mean value and the neutral value for each usability goal. The Null Hypothesis was tested to the 95% confidence interval and the result are shown in table 5.

Table 5 – Student t-test results on data

Usability goal	Mean	Max	Min	Neutral	SD	t-score (p value)
Impression	12.1	16	4	10	1.79	4.46 (p<0.05)
Efficiency	15.4	24	6	15	2.32	0.67 (p>0.05)
Learnability	16	20	5	12.5	2.5	5.38 (p<0.05)
Safety	16.2	20	5	12.5	2.68	5.36 (p<0.05)
Effectiveness	14	20	5	12.5	2.35	2.5 (p<0.05)

Max = maximum possible score for goal, Min = minimum possible score for goal, Neutral = neutral value for each goal, SD = standard deviation.

5.3.3 Qualitative results – User comments

By direct observation and unstructured interview it was possible to collate more qualitative data with respects to the user’s thoughts about prototype. As one would expect with a prototype there were both positive and negative comments about the interface as a whole as well as “bugs” in the system that were missed during the predictive modelling stage. Presented below in table 6 are the issues that were raised most frequently. These will be discussed in section 5.4.

Table 6 – Most common user comments regarding the prototype

Positive opinion	No.	User concern	No.
Direct praise of the concept	9	Time issues	8
Will help in performance of clinical duties	7	Will be of little use in clinical duties	2
Lead to greater patient safety	12	Hardware access	7
Straight forward to use	8	Aesthetics of the interface it self	4
		Bugs identified in the prototype	5

No. = number of individual users that made comments that fell into the categories

5.4 Discussion

In this section the results presented above will be discussed in more detail.

5.4.1 Authors initial impression

The objective statement of the project states:-

To design and test the usability of a prototype Human Computer Interface (HCI) for documenting repeated neurological examination of patients with spinal cord injury, spinal column fractures or compression of spinal nerves

- *To standardise the examination and method of recording the data*
- *To bridge the gap of knowledge between the differing experiences and skill levels within the multidisciplinary team with respect to the neurological examination*
- *To increase the detection rates of patients neurological deterioration and therefore improve the standard of care*

On completion of the user evaluations, the author had been given the impression that the user response was generally a positive one. As one would expect with a prototype there were a number of problems, major and minor, that had been identified by the users but the overriding opinion was that the project was a worthwhile exercise and that the final product would be welcomed into the clinical environment. These initial impressions required a more detailed analysis before any conclusions could be drawn from the usability testing. The results of this analysis have been displayed in section 5.3 and are discussed in the following text.

5.4.2 User Opinions – Quantitative data

As described in section 5.3.1.1, the user selection process was randomised to a certain extent but all currently worked in the same department and the author did bias the population with respect to the persona groups in order to more closely replicate the multidisciplinary team scenario that would be found in clinical practice.

It was felt that all the users coming from the same department would not have an effect on the outcome of the evaluation for a number of reasons. The department in question is a large department with over 50 medical staff alone working in the department at any one time. This gave a large population base from which users could be selected. Also it is the

nature of the junior doctors training structure that there is a rapid turn over of staff within a department, ranging from yearly for the SpR's to every 3 – 4 months for the foundation doctors. This means that the medical staff in the unit at anyone time will be made up from a population that vary in their level of experience and in the number of units in which they have worked. This therefore provided the ideal population from which to choose a user group.

The persona group that would be expected to use the interface most in the clinical setting would be the junior doctors (persona 3). It is usually this member of the team that would perform the majority of neurological examinations on the spinal injury patient, both at initial presentation and subsequent times. The majority of users chosen for the evaluation were therefore randomly selected from this group of staff.

The user opinion from this group was generally favourable. In figure 4, in which user opinion regarding the prototype is displayed graphically, all but one of the junior doctors scored above the neutral value, indicating a positive response to the project. The one junior doctor who did score low was user 6, who scored only 52 out of a possible 100. This was the lowest score given by some margin. During this individuals evaluation session there were problems regarding the hardware on which the prototype was running (author's laptop). The prototype would not run properly, the first time that this had happened, and the user therefore had to restart entering patient's details on more than one occasion. Although times were not formally recorded by the author during the evaluation process, the session with this user certainly took much longer than any other. User 6 first impression of the prototype was therefore not favourable and this is demonstrated in the low score. Due to the problem occurring during the evaluation being hardware in origin, the author could be justified in removing this user from the final analysis. In the clinical setting hardware problems do occur and it was felt that an evaluation of the software in this scenario would give a more "real world" opinion. The decision was therefore made to keep the user's evaluation of the system in the final analysis.

Personas 1 and 2 (Consultants and SpR's) were grouped together for the randomisation process because it was felt that both of these groups would use the system in their working practice in a similar manner. Inputting data using the interface would not be regularly performed by this group of users. The benefit that the interface gives these users is more in the knowledge that the patients under their care are having the examination

performed and recorded properly by the juniors and that any changes in examination findings will be conveyed to them at an appropriate time. On randomisation it so happened that no user from the Consultants were selected and as with the principles of randomisation this was accepted. The results from this user group were again favourable scoring well above the neutral value for user opinion.

Three user opinions fell below the neutral value in figure 4. The lowest score of 52 for user 6 is discussed above. The other two, both scores of 62 (users 10 and 15) represent the users taken from personas 4 and 5, an orthopaedic nurse and physiotherapist. During the evaluation it became apparent that these users did not have the necessary medical background required to perform the neurological examination in patients. Both these persona types spend more time with the patient on a day to day basis but their training is centred on identifying general changes in the patients condition (i.e. the legs of the patient are weaker) rather than assessing the finer points of the neurological examination (which specific myotomes are affected with this weakness). This made the inputting of data into the interface more difficult, with more reliance was put on to the help options available in the prototype, as large amounts of the information and the way it was presented was completely new to them. Taking this into consideration it would therefore be expected that the user opinion for the 2 users would be less favourable.

5.4.3 Usability Goals – Quantitative data

The aim of usability testing is to seek user opinion regarding the use of the prototype being tested, using both quantitative and qualitative methods. As stated before, this can be achieved by breaking usability down into a number of goals and then questioning the user about these specific goals. The statements presented on the questionnaire allowed the collection of quantitative data regarding these goals. This data is displayed in figure 5 and table 4.

By looking at the raw data displayed graphically in figure 5, it would seem that 24 out of the 25 statements used on the questionnaire evoked a positive response from the user. By collating the statement results for each individual goal, the mean scores for each goal can be calculated (table 4). Again it would appear that the user response with respect to the usability goals is generally positive, with only efficiency having a mean close to the neutral value (38.5 compared to 37.5). With descriptive analysis one should always be wary of using means to infer definite trends or results because it does not consider the

significance of the result. In order to allow more definitive conclusions to be drawn from the data, significance testing using inferential analysis in the form of a student t-test was performed on the data. The results of this analysis are shown in table 5. Using a 95% confidence interval, one is able to conclude that for four of the goals, Impression, Learnability, Safety and Effectiveness, the users did indeed respond favourably to the prototype.

Efficiency was the only goal tested that did not give a significant result at the 95% confidence interval. Is this a surprise or an expected result? A number of the statements used to assess efficiency were focused on the time it takes to use the interface, the most obvious being the statement “*the system allows me to accomplish the task more quickly*”. Figure 5 shows that the response to this statement was the lowest scoring, i.e. most negative, out of all the statements. The users are comparing the use of this interface, where the correct amount of patient data is being fully recorded, to the system currently in use, which is paper based, haphazard and often incomplete. One would therefore expect that the computer interface is always going to take longer to complete the task but as will be discussed below, this is a sacrifice that is acceptable.

5.4.4 Usability goals – qualitative data

The qualitative data collected during the interviews and during observation, helps to deepen and clarify the quantitative opinions obtained from the questionnaires. Certain trends, both positive and negative became apparent as more users were evaluated. Table 6 shows the major issues that were raised.

9 out of 15 users made comments that praised the concept of the project. There was a feeling that this interface has a place in the clinical setting and there was surprise that “no one had thought of the idea before”. This is consistent with the fact that the user’s impression of the system was favourable.

Seven of the users, consisting of those from persona 3 (junior doctor), stated that they thought that the system would help them in the performance of their clinical duties. As shown in the surveys in section 2.3, not all junior doctors know how to perform a full neurological examination. These users were able to use the help buttons available to supplement the knowledge that had they brought to the evaluation, ensuring that a complete examination was performed. Two users commented on leaving the evaluation

that they had learned several aspects of the examination that was required just by using the interface once and that they would carry this knowledge forward into their clinical practice.

Two users commented that the system would be of little use in their clinical duties. These were the users from personas 4 and 5 (nurse and physio) whose user opinion were scored low with the questionnaire. As commented above, these users do not perform the neurological examination regularly as part of their clinical duties and so neither thought the system would be useful for them on a personal level but it should be noted that both these users thought the project as a whole was a good idea.

To reinforce the positive response from the questionnaire with respect to the usability goal learnability and memorability, several users commented on how easy the system was to learn to use and that once the system had been used once or twice, subsequent use became more straightforward. The junior doctors who found themselves using the help buttons a lot to begin with were also noted to be using these aids much less frequently with experience.

It is important to state that the population from which the users were selected, would all be expected to have a more than rudimentary knowledge of computer use in their work environment. Investigation results for blood tests and x-rays are now routinely stored on computer data bases and these would be accessed several times a day by the users. One would therefore expect these users to quickly learn how to use a new system but on the other hand if the prototype had been of such a design making it more difficult to learn than databases already in use this would have quickly become apparent in the users opinions.

Safety is a key issue with any new system introduced that is directly involved in patient care. Therefore this usability goal is especially important. The quantitative data supports that fact that the prototype is considered safe to use and this is reinforced with the user comments. 12 out of the 15 users all stated during the interview that they thought the system was a safer way manage the neurological examination of patients than the current system and it was felt by the majority of these that it would lead to less clinical errors.

The qualitative data again corresponds to the quantitative finding with respect to efficiency. Concerns were raised by several of the users regarding the extra time taken to input the data and how this would impact on the daily workload of the individual. In conjunction with this were the concerns raised by some users regarding the lack of hardware available on the wards. Some orthopaedic wards still only have 1 or 2 terminals which are used by all members of staff including ward clerks, nurses and doctors. In the clinical setting, the situation of the examining doctor not have access to a terminal to record the examination findings for a period of several minutes, is a distinct possibility, again adding more time to the process.

The two preceding paragraphs raise an important issue. Safety is paramount, with thorough examinations being performed and the findings being recorded fully but this is automatically going to take longer to do when compared to an incomplete examination with a couple of paragraphs scribbled down in the paper notes. A balance between safety and efficiency needs to be struck but because patient safety can never be compromised it is only the efficiency of the system that can be adjusted. Users to a certain extent are going to have to accept that the interface is going to take longer to use. It is the responsibility of the design team to make any final interface as efficient as possible thereby reducing the extra time needed to use the system. This process involves both the interface software and the hardware on which it is run. This will be discussed further in the section entitled future work.

Comments were also made by some of the users, especially the more experienced, regarding the aesthetics of the prototype. Criticism was mainly directed towards the final results page, which was felt to be unclear and potentially confusing. The tabulation of results, giving numeric values to findings such as reflexes was described as unsatisfactory because this is not how these results are recorded historically. One user commented that “it was a shame to have a system to detect any changes in a neurological examination only for these results to be missed because of a poor method of displaying them”. Also during the evaluation, several “bugs” were identified which had been missed during the development of the prototype. These ranged from the simple such as spelling mistakes, an example of which is the word supination having been spelt wrong, as shown in the screen shot in section 4.4.4.4 (intentionally left uncorrected by the author in this work for this purpose), to more major problems such as navigation issues. Although these concerns raised are valid it is important not to lose sight of the fact that the interface at present is

just an interactive prototype. A prototype represents a simplified model of a final design and its function is to allow the designers to make changes to the design before the final development is too advanced. A large amount of time was therefore not expended on aesthetics which were considered non essential to the function of the prototype. An example of this is the results page, which although was not well constructed, was of good enough standard to not affect the usability testing.

The same response can be directed towards the “bugs” that were discovered during the evaluation. It is important that these problems are identified during the prototype testing so that they can be addressed before the project becomes too advanced. Changing any problems in a system that is near its final form is more major issue in both time and expense. In fact if no problems had been identified during the evaluation, one would have to question the thoroughness of that evaluation.

5.5 Summary

The aim of this chapter has been to evaluate the usability of the prototype interface. Usability was broken down into a number of well defined goals. A number of methods were then used to collect both quantitative and qualitative data focusing on these specific goals. This data was then analysed using descriptive and inferential methods to decide if the prototype had achieved a satisfactory level of usability.

The prototype has been shown to be easy to learn how to use and once learnt, easy to remember how to use. It is effective in achieving what it is supposed to do and users feel positive about using the system in a clinical setting. It has also been shown that it is considered a safe system to use with potential to prevent patient complications due to delays in detecting neurological deterioration.

At present it would appear that using the prototype is a less efficient way of working but this was expected given the more formal structure of computer based records compared to paper based systems. This formal structure does not allow corners to be cut for the sake speed but it is this rigidity that makes the computer based system safer compared to paper based records. It will be the responsibility of the design team to attempt to improve the efficiency of the system without sacrificing any of the positive features of the prototype (especially safety) during future development of the interface.

6 Conclusions and future works

The following section presents the conclusions that can be drawn from data analysis and discusses the future work that may ensue as a result of the project.

6.1 Conclusions

The use of a human computer interface, such as the prototype design for this project, will standardise the performance and documentation of the neurological examination in patients presenting with spinal pathology.

The interface will act as an education tool for those less experienced members of the multidisciplinary team, who are expected to regularly perform the neurological examination on patients as part of their clinical practice.

The interface has the potential for improving the detection rate of neurological deterioration in a patient with spinal pathology, leading to an improved chance of a more favourable prognosis.

6.2 Future work

The work performed so far has resulted in an interactive prototype that fulfils the project's objectives statement (section 4.2). By definition the prototype is a simplified model of the final design and a substantial amount of work, both in design and testing, is required prior to a fully working system being integrated into the clinical workplace. Issues have arisen, involving the software design and potential hardware problems that must be addressed before a final design is completed. These are discussed below as well as possible avenues of research that can be explored in any future work.

6.2.1 How the interface displays information to the user

During the usability testing, several users had commented that the interface displayed some of the information in a confusing manner. Most criticism was directed to the final results page which presents the changes found in the neurological examination in a basic tabulated form. The prototype gives numerical values to all parameters which is not appropriate in all cases, an example being reflexes which are historically documented as normal, absent or brisk. As discussed in section 5.4.4, the minimum time possible was put into the aesthetics of certain elements of the prototype that were considered non

essential when producing a functioning system that could be used for usability testing. It was always accepted by the design team that in order to develop the final interface a large amount of work would be required on the general aesthetics of the design.

The issue of how any final interface should display information was discussed further when the author presented the results of the usability testing at the annual British Orthopaedic Association national congress, a national meeting of orthopaedic surgeons, held in Liverpool in September 2008 (76). The general feeling amongst members of the audience, which included several professors of orthopaedics and consultants all with specialist interests in spinal surgery and spinal injuries, was that the information would need to be displayed in a manner not far removed from the ASIA scoring system (Appendix 2) because this system has been successfully used as a clinical tool in spinal units throughout the NHS. This should be taken into consideration in any further designs because in order to gain clinical acceptance it is imperative to have support of the spinal consultant body.

6.2.2 Hardware availability

Concerns were raised during usability testing regarding the availability of hardware on standard orthopaedic wards. Ward based PC's, being shared by multiple different types of staff does not lead to efficient use of time and with more computer based records being introduced into the NHS this will only get worse. Trusts have been solving this potential problem in two main ways. The simplest solution is just to increase the numbers of terminals available on the ward, which taken to the extreme is to have individual patient terminals, one for each bed. The second solution is the use of mobile devices which can then be linked to the main system.

Development issues that may need to be addressed with any future work will include the type of hardware that it used on. Work on usability testing of the prototype has so far has concentrated on a format for a ward based PC. Design of an interface suitable for a mobile device will need to address other potential issues such as the small screen size of the device, organising the interaction between different devices (i.e. mobile device and the system base pc) and the need to test the usability of the system as a whole rather than the individual devices. Further discussion regarding the use of mobile devices is beyond the scope of this project at present.

6.2.3 Prototype evolution

The prototype requires significant further development in order to achieve the criteria expected for an interface that can be used in the clinical setting. The first step will need to be further discussion with consultants running some of the country's spinal injuries units to clarify how they would like any interface to perform beyond the level achieved by the prototype at present. Once these expectations have been collated, the design team will then need to decide on how the prototype will evolve. As discussed before (section 4.3.3), the prototype can be used in one of two ways. By building further design elements onto the prototype, testing each stage as it is completed, the prototype can evolve into the final design (evolutionary prototyping) or design for the final interface can be started from the beginning and the prototype is just used as a stepping stone towards this final design (throwaway prototyping). Only when the design team meet to discuss the advancements needed, will the more appropriate of these two methods of prototyping become apparent.

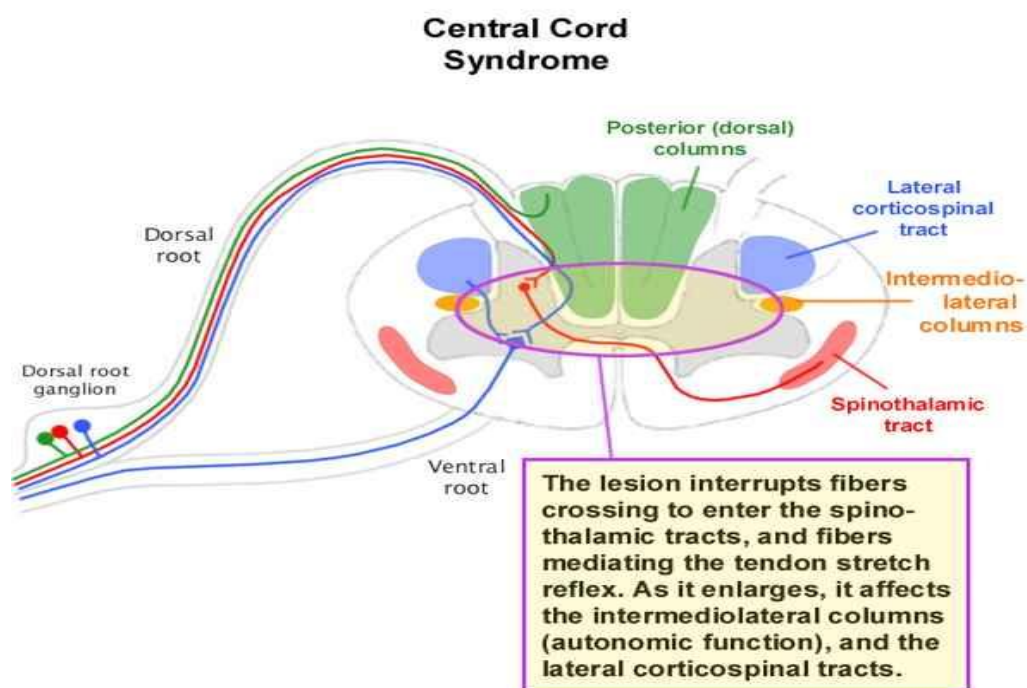
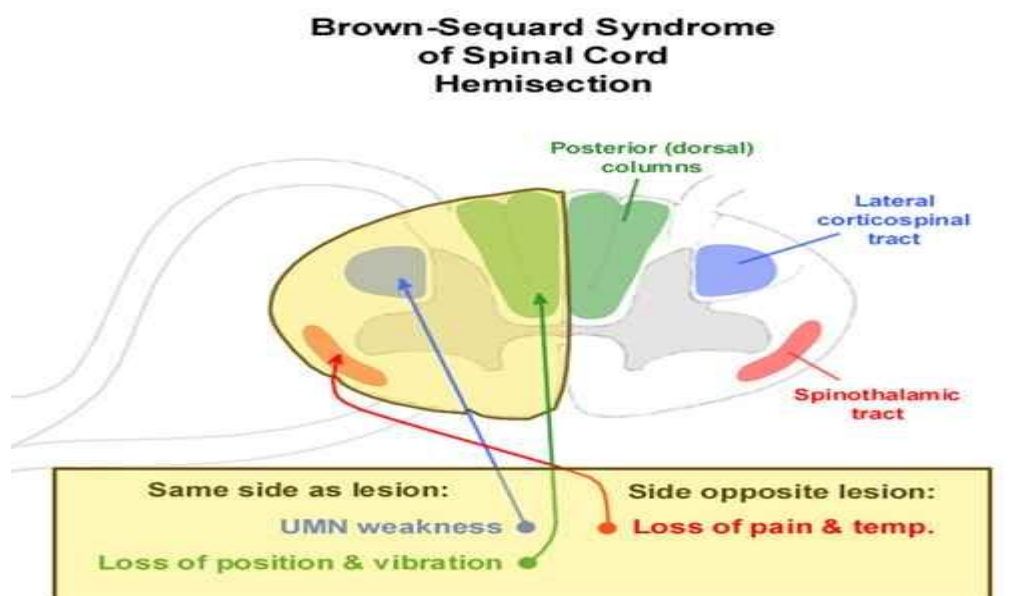
6.2.4 Further evaluation

Once the design has reached a level, beyond prototyping, where it is considered safe to use in the clinical setting, it will require beta testing. A beta test or field trial is where the final product undergoes early release to a few users. This type of testing has an "ecological validity" with real people using the product in real environments to complete real tasks (70). Beta testing tends not to be used to gather information about usability because the quality of data about usability collected using beta tests is poor. This is due to a number of reasons. Set tasks required for usability testing cannot be chosen, the tasks that are performed are what the user comes across during the test period and users tend not to be observed whilst performing these tasks. The feedback is also unsystematic with users only reporting what they remember or choose to report in an after the fact manner. In the further work for the project, the beta test will need to be performed in a centre with a high throughput of spinal injuries so that the testing can take place in an appropriate period of time. The unit must also have protocols for the examination of these patients in place, i.e. regular use of ASIA scoring, to run parallel to the interface. This will allow the interface to be tested in the clinical setting whilst maintaining patient safety. An ideal environment for the beta test will therefore be a spinal injuries unit rather than a standard district general hospital. Therefore one or more of these units will need to be approached to ensure they are willing to consider using such a system before significant amounts of time and resources are used in developing the interface.

7 Appendices

7.1 Appendix 1: Pictorial Demonstration of Brown-Sequard Hemisection and Central Cord Syndrome.

(Diagrams used taken from reference 77)



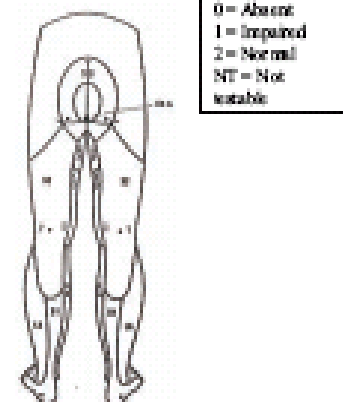
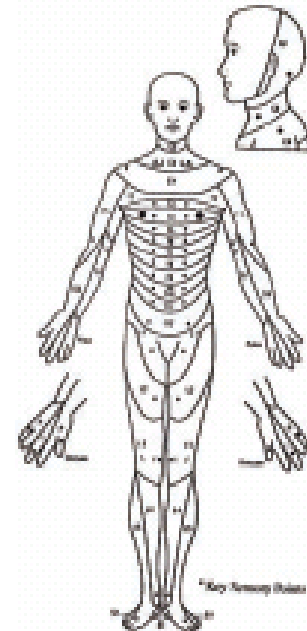
7.2 Appendix 2: The Asia Chart.

Name:
DOB:

Date of Onset:
Neurological Level:

Hosp. No:
Bony Level:
NEUROLOGY Chart

Date						
	Motor		Touch		Pain	
Time	R	L	R	L	R	L
MOTOR						
Shoulder Elevators C3, 4						C2
Abductors C5, 6						C3
Adductors C5-T1						C4
Elbow Flexors C5, 6						C5
Extensors C2, 8, T1						C6
Wrist Flexors C6, 7, 8						C7
Wrist Extensors C6, 7, 8						C8
Finger Flexors C7, 8, T1						
Finger Extensors C7, 8						T1
Hand Intrinsic C8, T1						T2
Thumb Flexors C7, 8, T1						T3
Thumb Extensors C7, 8						T4
ABD. DIG. MUS. C8, T1						T5
Abdominal Muscles: Upper						T6
Lower						T7
Hip Flexors L2, 3						T8
Extensors L5, S1, 2						T9
Abduct. L4, 5, S1						T10
Adduct. L3, 4						T11
Knee Flexors L4, 5, S1, 2						T12
Knee Extensors L2, 3, 4						
Ankle DF L4, 5, S1						L1
PF S1, 2						L2
Toe Flexors L5, S1, 2						L3
Extensors L4, 5, S1						L4
REFLEXES						L5
BICEPS						
TRICEPS						S1
SUPINATOR						S2
ABDOMINAL						S3
KNEE						S4-5
ANKLE						
PLANTARS						Vibration
EC REFLEX						Joint Position
ANAL						
ASIA SCORE						(/56) Max each
Total ASIA score		(/10)	(/11)	(/12)		



0 = Absent
1 = Impaired
2 = No rail
NT = Not testable

Motor Score
0 = total paralysis
1 = palpable or visible contraction
2 = active movement, gravity eliminated
3 = active movement, against gravity
4 = active movement, against one resistance
5 = active movement against full resistance

Sensory Score
* Note that a light sensation to pin prick is calculated as = 0
* Dark Grey areas are ASIA. Groups of muscles calculated in this section

7.3 Appendix 3: Patient Questionnaire

The Doctor-Patient Relationship: A Patient Questionnaire

In order to keep doctors working hours with in the European Working Time Directive many hospitals have made junior doctor rotas a shift pattern rather than an on-call rota. This means that it is possible that more than 1 doctor of the same rank will be responsible for your care during the first 24 hours of your admission.

Please could you answer the following questions:-

1) In your opinion do you feel it would be better for only 1 doctor to be responsible for your care on your admission to hospital (Taking the History, Examining, Ordering investigations, Chasing results, reviewing patient if necessary)?

Yes

No

Don't Know

2) Do you agree with the following statement?

The relationship between a patient and the junior doctor looking after them is important

Strongly agree

AgreeDisagree

Strongly disagree

Please note all answers are strictly confidential and are to be used in a research project.

7.4 Appendix 4: Example of Chart Given to Junior Doctors to Test Anatomical Knowledge

Correct Answers included on this version of the table

Nerve Root	Myotome	Dermatome
C5	Elbow Flexion	Upper Lateral Arm
C6	Wrist Extension	Lateral Forearm
C7	Elbow Extension	Middle Finger
C8	Finger Flexion	Medial Forearm
T1	Finger Abduction	Medial Upper Arm
L2	Hip Flexion	Upper Anterior Thigh
L3	Knee Extension	Lower Anterior Thigh
L4	Ankle Dorsiflexion	Medial Calf
L5	Extensor Hallucis	Lateral Calf and Dorsum Foot
S1	Ankle Plantar Flexion	Sole Foot
S2	NONE	Back of Leg
S3-5	NONE	Around Anus

7.5 Appendix 5: Possible Case Scenarios.

Scenario 1 – The Ideal Situation

At 6 am on a Saturday morning, a 25 year old male is involved in a Road Traffic Accident. He is a passenger in a vehicle that hits a tree. He is wearing a lap safety belt and so suffers a flexion type injury to his lower spine. The patient is taken to hospital complaining of lower back pain. After assessment by the Accident and Emergency team he is diagnosed with an isolated fracture to one of the vertebrae in his lumbar spine and referred to orthopaedics.

The hospital to which he admitted has a dedicated spinal injuries unit and he is transferred there from the Accident Department at 8am. At this stage he is examined by the on-call orthopaedic team. A thorough and systematic neurological examination is performed and full documentation is recorded using the spinal unit's protocol (for example an ASIA chart). At this stage the patient is neurologically intact. The patient undergoes a scan to further image the fracture. Following this scan it is decided that the patient will need surgery to stabilise the fracture. The surgery is planned for Monday morning and until then he will be nursed in flat in bed.

At 9pm on the same day, the patient complains to the nursing staff that his legs feel funny. The nursing staff noted from the detailed examination records that the patients had no symptoms in his legs initially and therefore calls the on-call orthopaedic doctor. A member of the orthopaedic team who examined the patient in the morning returns to see the patient. The thorough neurological examination is repeated in exactly the same systematic way as before. A loss of sensation up the back of the legs and in the perineum is noted. There is concern that the patient is developing the early signs of Cauda Equina compression. The patient undergoes an emergency MRI scan which shows an expanding epidural haematoma which as suspected is compressing the Cauda Equina. Emergency surgery is performed with the Epidural haematoma being evacuated and the spinal fracture stabilised.

The patient makes a full recovery with no long term neurological deficit because the epidural haematoma was decompressed before permanent damage to the spinal nerves occurred.

Scenario 2 – The scenario to avoid!

At 6 am on a Saturday morning, a 25 year old male is involved in a Road Traffic Accident. He is a passenger in a vehicle that hits a tree. He is wearing a lap safety belt and so suffers a flexion type injury to his lower spine. The patient is taken to hospital complaining of lower back pain. After assessment by the Accident and Emergency team he is diagnosed with an isolated fracture to one of the vertebrae in his lumbar spine and referred to orthopaedics.

The hospital to which he is admitted has a spinal surgeon but no spinal injuries unit. The orthopaedic wards are full, and therefore the patient is admitted to a general surgical ward which has free beds. The patient is examined by the admitting orthopaedic team. There are no protocols to follow.

The admitting doctor performs a neurological examination and determines that the patient is neurologically intact. The documentation, which is made by one of the junior members of the team, is incomplete with motor power and sensation recorded only as “grossly intact”. The specific muscles tested for power and areas of the leg tested for sensation are not recorded.

The patient undergoes a scan to further image the fracture. Following this scan it is decided that the patient will need surgery to stabilise the fracture. The case will be discussed with the spinal consultant on Monday and the timing of surgery planned, until then the patient will be nursed with flat bed rest.

At 9 pm the same day, the patient complains to the nursing staff that his legs feel funny. The nursing staff are not used to looking after orthopaedic patients especially those with spinal injuries. The notes are reviewed and as the patient still appears to have grossly

intact neurology it is decided to wait until the on call doctor comes round to the ward before speaking to them about the patient.

The hospital to which the patient has been admitted runs a shift system for the junior doctors in order to comply with the European working time directive. This means that the doctor who eventually comes to the ward is a member of the Hospital at Night Team (HANT) and is covering all the surgical specialities. It is the first time that this doctor, who is a newly qualified F1, has ever met the patient. He is yet to do an Orthopaedic attachment in his training. This doctor examines the patient and ascertains that there is full power in the legs and intact sensation. This appears to correspond with the examination findings of grossly intact power and sensation from the admission. The patient is reassured that everything is ok and that he will be reviewed again in the morning.

Unfortunately this doctor's examination is incomplete, the back of the legs and perineum were not tested because the examining doctor has forgotten to test this area during his neurological examination. Also it wasn't documented that this was performed on admission and there are no protocols to follow, so this doctor's error goes undetected. The signs of impending Cauda Equina compression have been missed.

The following morning, the patient starts to get significant leg pain bilaterally with worsening loss of sensation now going down both legs. The on call orthopaedic doctor is called and on examination the loss of sensation in both legs and especially around the perineum is detected. At this stage the fact that the patient had gone into painless retention of urine over night is also noted. The diagnosis of Cauda Equina is now made. The patient undergoes an emergency MRI and when this shows an expanding epidural haematoma the spinal surgeon is contacted.

The patient undergoes emergency surgery but unfortunately fails to make a full recovery. The delay in diagnosis has caused permanent nerve damage and the patient has been left with poor bladder control, and erectile dysfunction.

Scenario 3 – The HCI in use

At 6 am on a Saturday morning, a 25 year old male is involved in a Road Traffic Accident. He is a passenger in a vehicle that hits a tree. He is wearing a lap safety belt and so suffers a flexion type injury to his lower spine. The patient is taken to hospital complaining of lower back pain. After assessment by the Accident and Emergency team he is diagnosed with an isolated fracture to one of the vertebrae in his lumbar spine and referred to orthopaedics.

The hospital to which he is admitted has a spinal surgeon but no spinal injuries unit. The orthopaedic wards are full, and therefore the patient is admitted to a general surgical ward which has free beds. The patient is examined by the admitting orthopaedic team.

The results of the neurological examination are recorded on to computer using the Human Computer Interface (HCI). The patient undergoes a scan to further image the fracture. Following this scan it is decided that the patient will need surgery to stabilise the fracture. The case will be discussed with the spinal consultant on Monday and the timing of surgery planned, until then the patient will be nursed with flat bed rest.

At 9 pm the same day, the patient complains to the nursing staff that his legs feel funny. The nursing staff are not used to looking after orthopaedic patients especially those with spinal injuries. The nurse use the HCI to review the patient's previous examination findings. The HCI makes it clear to the nurse that there has been a change in the patient's neurology and so an immediate review by a doctor is requested.

The hospital to which the patient has been admitted runs a shift system for the junior doctors in order to comply with the European working time directive. This means that the doctor who is called is a member of the Hospital at Night Team (HANT) and is covering all the surgical specialities. It is the first time that this doctor, who is a newly qualified F1, has ever met the patient. He have yet to do an Orthopaedic attachment in their training.

The doctor examines the patient and ascertains that there is full power and normal sensation. On using the HCI to record the examination findings the doctor is reminded that examination of the back of legs and perineum is required. He goes back to examine these areas on the patient and detects the loss of sensation to the perineum. The change in examination findings are detected by the computer when the new data is inputted and the doctor is made aware that action needs to be taken.

The patient is discussed with senior orthopaedic doctors and an urgent MRI is performed. The scan shows an expanding haematoma and after discussion with the spinal surgeon, an emergency operation is performed that night.

The patient makes a full recovery with no long term neurological deficit because the epidural haematoma was decompressed before permanent damage to the spinal nerves occurred.

I found it easy to make system do what I needed it to do.				
The system was responsive to my inputs.				
I found the interaction with the system cumbersome.				
The system reacted quickly enough to my selections.				
The system allowed me to complete the task more quickly				
<p>Additional comments about whether you feel in control:-</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>				
Learnability and memorability - <i>the degree to which the user feels that the HCI is easy to become and remain familiar with.</i>	Strongly Disagree	Disagree	Agree	Strongly Agree
Learning to use the system was straight forward.				
I would have time to learn a system like this in a clinical setting.				
It would be easy to demonstrate this system to a colleague.				
Once learnt it would be easy to remember how to use the HCI even if used infrequently.				
I would not need regular sessions on how to use the system.				
<p>Additional comments about how easy you felt the software was to become familiar with:-</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>				
Safety – <i>does the user feel safe using the system.</i>	Strongly Disagree	Disagree	Agree	Strongly Agree
The system made sure that no aspect of the examination was missed.				
The user felt reassured that the examination had been documented fully.				
The user felt that someone repeating the examination would note any changes.				
The user felt that if they repeated an exam performed by another				

they would not miss any changes.				
The system will lead too less clinical errors.				

Additional comments about how helpful the system is in assisting you resolve a situation:-

.....

.....

.....

.....

.....

.....

.....

.....

Effectiveness - <i>the degree to which the user feels that they can complete the task while using the system.</i>	Strongly Disagree	Disagree	Agree	Strongly Agree
Using HCI would NOT be of use to me in my job.				
Using the HCI would get in the way of the task I was undertaking.				
When using HCI I found it difficult to obtain the information I needed.				
Using HCI will enable me do my job effectively.				
When using HCI it is straightforward to get to the information I needed.				

Additional comments about how effective you feel the software was:-

.....

.....

.....

.....

.....

.....

.....

.....

--

7.7 Appendix 7 – Raw data collected from user evaluation

I1	3	3	3	3	3	2	3	3	3	2	4	3	3	3	2
I2	3	3	3	3	3	2	3	4	3	3	4	2	3	3	2
I3	3	3	3	3	3	2	3	4	3	3	3	3	4	3	3
I4	4	3	3	3	3	2	3	4	3	3	4	3	4	3	3
E1	3	3	3	3	4	2	3	3	3	2	3	2	3	3	2
E2	3	3	3	3	3	1	3	3	3	2	4	3	4	2	2
E3	3	3	3	3	3	2	3	3	3	3	4	3	3	3	3
E4	3	2	2	3	3	2	2	3	3	2	3	3	4	3	2
E5	3	2	2	3	2	2	2	3	3	3	3	2	3	2	3
E6	1	1	2	1	2	1	2	2	2	2	2	2	2	1	1
L1	4	3	3	3	4	3	3	4	3	2	4	4	4	4	3
L2	4	3	3	3	3	3	3	4	3	3	3	3	4	2	2
L3	3	3	3	3	4	2	3	3	4	2	3	3	4	3	2
L4	3	3	3	3	4	3	3	4	3	2	4	3	4	3	2
L5	4	3	3	4	4	3	3	3	4	2	4	4	4	3	3
S1	4	3	3	4	3	2	3	4	3	3	4	3	4	3	3
S2	3	2	3	3	3	2	3	4	4	3	4	3	4	4	3
S3	4	3	3	4	3	2	3	4	4	3	4	3	3	3	3
S4	4	3	3	4	3	2	3	4	4	3	4	3	3	3	3
S5	3	3	3	3	3	2	3	4	4	2	4	3	4	3	4
e1	3	3	3	3	3	2	3	4	4	2	4	3	2	3	2
e2	2	2	2	3	3	2	3	3	3	2	3	3	3	2	2
e3	3	3	4	3	3	2	3	3	3	3	3	2	2	2	2
e4	2	3	3	3	3	2	3	4	4	2	4	3	2	2	3
e5	3	3	3	3	3	2	3	3	3	3	4	3	3	3	2

I = impression, E = efficiency, L = learnability, S = safety, e = effectiveness

8 References

- 1) Epidemiology of incident of spinal fracture in a complete population. Hu R et al. *Spine* 1996 Feb 15;21(4): 492 -499
- 2) Oxford Textbook of Orthopaedics and Trauma. Volume 3. *Oxford University Press* 2002
- 3) Handbook of Fractures 2nd Edition. Koval K. *Lippincott Williams and Wilkins* 2002
- 4) The Initial Care and Transfer of Patients with Spinal Cord Injuries. *British Orthopaedic Association Guidelines, January 2006.*
- 5) Epidemiology of Spinal Cord Injury. Kurtzke JF. *Neurol Neurocir Psiquiatr*, 1977; 18(2-3 suppl):157-91
- 6) Global Summary of Spinal Cord Injury, Incidence and Economic Impact. *ICCP March 2001(revised July 2004)*
- 7) Seat belts: Advice and Information. Road Safety Information. *RoSPA April 2005*
- 8) Understanding Functional Changes in the CNS following Cranial and Spinal Trauma. Mowle D. *Surgery Volume 18:9 Sept 2000 Pg 212 - 213*
- 9) Advanced Trauma Life Support for Doctors. *American College of Surgeons Committee on Trauma.*
- 10) A Charter for Support: The Spinal Injuries Association Recommendations regarding NHS treatment of people confirmed, suspected or potentially experiencing spinal cord injury. *Spinal Injuries Association, London 1997*
- 11) Back Pain and Sciatica. Frymoyer JW et al. *N Eng J Med* 1988; 318: 291- 300.

- 12) The Management of Degenerative Lumbar Spine Disease. Haden N et al. *ACNR. Volume 4 number 6 Jan/Feb 2005.*
- 13) Cauda Equina Syndrome: Is it a Surgical Emergency. Nascone JW et al. *U.P.O.J Vol 12 Spring 1999. Pg 73-76*
- 14) Cauda Equina Syndrome Secondary to Lumbar Disc Herniation: A Meta-analysis of Surgical Outcomes. Ahn UM et al. *Spine 2000 June 15; 25(12): 1515-22*
- 15) New Warning Over NHS Staff Shortages. www.politics.co.uk 01/11/2004
- 16) NHS job shortages leaves physios walking a tightrope. www.societyguardian.co.uk 28/11/2005
- 17) New Doctors and Nurses head for the Dole or to Australia. www.telegraph.co.uk 02/10/2006.
- 18) Hospital Doctors – Junior Doctors Hours. *BMA News archive May 2006.*
www.BMA.org.uk
- 19) European Working Time Directive for Junior Doctors. Shah PR et al.
www.edu.rcsed.ac.uk/lectures
- 20) Implications for health and safety of junior doctors' working arrangements. *JDC report July 2000.* www.BMA.org.uk
- 21) Advanced Examination Techniques in Orthopaedics. Edited by Harris N. Greenwich Medical Media Limited 2003
- 22) Patient Focus – How health information flows to support patient care. *Health informatics unit.* www.hiu.rcplondon.ac.uk April 2005

- 23) Standards in medical record keeping. Mann R. *Clin Med* 2003; 3: 329-32
- 24) JISC Extended Glossary (2006). www.jisc.ac.uk/uploadeddocuments/eAssess-Glossary-Extended-v1-01.pdf
- 25) Teaching and Learning via the Network: Virtual Instructional Classroom Environment in Science (VICES). Graziadei W. *Coalition for Network Information*. 1993
- 26) Building Asynchronous and Synchronous Teaching-Learning Environments: Exploring a Course/Classroom Management System Solution. Graziadei W. www.horizon.unc.edu/projects/monograph/CD/Technological_Tools/Graziadei.asp. 1997
- 27) Reflections on the Use of Blended Learning. Heinze A. *Education in a Changing Enviroment*. 2004
- 28) Blended Learning Systems: Definition, Current Trends and Future Directions. Graham C. *Handbook of Blended Learning: Global Perspectives, Local Designs*. pp 3 – 21. 2005
- 29) Blended Learning: Uncovering its Transformative Potential in Higher Education. Garrison D. et al. *The Internet and Higher Education* 7: 95 – 105. 2004
- 30) Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, discovery, problem-based, experiential and inquiry-based teaching. Kirschner P. *Educational Psychologist* 41 (2): 75 -86. 2006
- 31) Guidelines for Learning/Teaching/ Tutoring in a Mobile Environment. O'Malley et al. www.mobilearn.org/download/results/guidelines.pdf. 2003.
- 32) M-Learning. Harriman G. *E-Learning Resources*. www.grayharriman.com. 2005

- 33) The Effectiveness of a Clinically Integrated E-Learning Course in Evidence-Based Medicine: A Cluster Randomised Controlled Trial. Kulier R. et al. *BMC Medical Education*. 2009. May
- 34) Computer-Based Teaching is as Good as Face to Face Lecture-Based Teaching of Evidence-Based Medicine: A Randomised Controlled Trial. Davis J. *BMC Medical Education*. 2007 July.
- 35) Satisfaction With Web-Based Training in an Integrated Healthcare Delivery Network: Do age, Education, Computer Skills and Attitudes Matter? Atreja A. et al. *BMC Medical Education*. 2008 Oct.
- 36) Predictors of Student Satisfaction in Distance-Delivered Graduate Nursing Courses: What Matters Most? Debourgh G. *Journal of Professional Nursing* 2003 May – Jun; 19(3):149-63.
- 37) New Guide for NHS Staff to Select and Implement a Virtual Learning Environment. www.dh.gov.uk. 2004
- 38) E-Learning in Surgical Education and Training. Larvin M. *ANZ Journal of Surgery*. 2009 Mar; 79(3): 133-7.
- 39) A Service Orientated Architecture for a Collaborative Orthopaedic Research Environment. Makola D et al. *eprints.ecs.soton.ac.uk* 2006
- 40) A Virtual University Infrastructure for Orthopaedic Surgical Training with Integrated Simulation. Grange S. *Engineering, Mathematics and Computing, University of Exeter*, 2006
- 41) Radiology Goes Filmless. Alexander S. *Healthcare Informatics*. 2001 Apr; 18 (4): 65 – 8.

- 42) The Reality of Picture Archiving and Communication Systems (PACS): A Survey. Bauman R. et al. *Journal of Digital Imaging*. 2000 Nov; 13(4): 157 – 69.
- 43) A Comparison of Conventional Film, CR Hard Copy and PACS Soft Copy Images of the Chest: Analyses of ROC Curves and Inter-Observer Agreement. Weatherburn G. et al. *European Journal of Radiology*. 2003 Sep; 47(3): 206 – 14.
- 44) Comparison of a PACS Workstation With Laser Hard Copies for Detecting Scaphoid Fractures in the Emergency Department. Khalig W. et al. *Journal of Digital Imaging*. 2008 Nov 7 (Epub ahead of print)
- 45) The Effect of a Picture Archiving and Communication System (PACS) on Diagnostic Performance in the Accident and Emergency Department. Weatherburn G. et al. *Journal of Accident and Emergency Medicine*. 2000 May; 17(3): 180 – 4.
- 46) The Effect of Picture Archiving and Communications Systems on the Accuracy of Diagnostic Interpretation of Paediatric Emergency Physicians. Gouin S. *Academic Emergency Medicine*. 2006 Feb; 13(2): 186 – 90.
- 47) A Hospital-Wide Picture Archiving and Communication System (PACS): The Views of Users and Providers of the Radiology Service at Hammersmith Hospital. Watkins J. *European Journal of Radiology*. 1999 Nov; 32(2): 106 – 12.
- 48) Picture Archiving and Communication Systems: A Multicentre Survey of Users Experience and Satisfaction. Tan S. et al. *European Journal of Radiology*. 2009 Jun 10 (Epub ahead of print)
- 50) Relationship Between Cutting Errors and Learning Curve in Computer-Assisted Total Knee Replacement. Manzotti A. et al. *International Orthopaedics*. 2009 Jun 10 (Epub ahead of print)

- 51) Improved Accuracy of Computer Assisted Glenoid Implantation in Total Shoulder Arthroplasty: An In-vitro Randomised Controlled Trial. Nguyen D. et al. *Journal of Shoulder and Elbow Surgery*. 2009 May 29 (Epub ahead of print).
- 52) Computer Assisted Surgery for Acetabular Cup Positioning in Total Hip Arthroplasty: Comparative Prospective Randomised Study. Parratte S. et al. *Rev Chir Orthop Reparatrice Appar Mot*. 2007 May; 93(3): 238 – 46.
- 53) Validation and Usefulness of a Computer Assisted Cup Positioning System in Total Hip Arthroplasty. A Prospective, Randomised Controlled Study. Parratte S. et al. *Journal of Bone and Joint Surgery American*. 2007 Mar; 89(3): 494 – 9.
- 54) Computer Assisted vs. Conventional Mechanical Jig Technique in Hip Resurfacing Arthroplasty. Resubal J. et al. *Journal of Arthroplasty*. 2009 Apr; 24(3): 341 – 50.
- 55) www.telemedicine.com
- 56) Health Informatics – Electronic Health Record – Definition, Scope and Context. *ISO/DTR 20514, 2004*.
- 57) Definition, Structure, Content, Use and Impacts of Electronic Health Records: A Review of the Research Literature. Hayrinen K et al. *International Journal of Medical Informatics* 2007.
- 58) Evaluating Physician Satisfaction Regarding User Interactions with an Electronic Medical Records System. Sittig DF et al. *Proc AMIA Symp*. 1999; 400-404
- 59) Impact of a Computer -based Patient Record System on Data Collection, Knowledge Organisation and Reasoning. Patel VL. *Journal of the American Medical Informatics Association* 2000; 7: 569-585

- 60) Effects of Computer-based Clinical Decision Support Systems on Clinician Performance and Patient Outcome: A Critical Appraisal of Research. Johnston ME et al. *Annals of Internal Medicine*. 15 Jan 1994; Vol 120 issue 2: 135-142.
- 61) Interaction Techniques for Using Handhelds and PC's Together in a Clinical Setting. Alsos O. *Nordi.CHI 14 – 18 Oct 2006*
- 62) The Use of the Personal Digital Assistant (PDA) Among Personnel and Students in Health Care: A Review. Lindquist A. et al. *Journal of Medical Internet Research*. 2008 Oct - Dec; 10(4): e31.
- 63) Visualisation of Patient Data of Different Granularities on Mobile Devices. Chittaro. L. *AVI'06 2006 May 23-26, Venezia Italy*
- 64) Implementing Information Technology in a Behavioural Health Setting. Puskar K. et al. *Issues Ment Health Nurs*. 2004; 25(5): 439 – 50.
- 65) Supporting Information Access on a Hospital Ward by a Context Aware Mobile Electronic Patient Record. Skov M et al. *Pers Ubiquit Comput (2006) 10: 205 -214*.
- 66) Portable Computing in Psychiatry. Luo J. *Can Journal Psychiatry*. 2004 Jan; 49(1): 24 – 30.
- 67) A Review and a Framework of Handheld Computer Adoption in Healthcare. Lu Y et al. *International Journal of Medical Informatics*. 2005 Jun; 74(5): 409 – 22
- 68) Implementing a Wireless Network of PDA's in a Hospital Setting. Turner P. et al. *Pers Ubiquit Comput*. 2005; 9: 209 – 17.
- 69) Interaction Design. Beyond Human-Computer Interaction. Rogers Y, Sharp H and Preece J. 2002 *John Wiley and Sons Inc*

- 70) A Practical Guide to Usability Testing. Dumas J, Redish J. *Ablex Publishing Corporation, 1993.*
- 71) Paper Versus Computer Implementations as Mockup Scenarios for Heuristic Evaluation. Nielson J. *Proceedings of INTERACT '90, 1990: 315 - 320*
- 72) Free online dictionary of computing 2005
- 73) HCI Lecture Notes: Evaluation Methods. School of Electronics and Computer Science, University of Southampton, UK. Wills, G. B., 2005a
- 74) The Dynamics of Interviewing. Kahn R and Cannell C. *1957 John Wiley and Sons*
- 75) The Design and Evaluation of Industrial Hypermedia. *PhD Thesis*, School of Electronics and Computer Science, University of Southampton, UK. Wills G B 2000.
- 76) British Orthopaedic Association Annual Congress, BT Convention Centre, Liverpool 16 – 19 September 2008.
- 77) The Spinal Cord. Introduction to Clinical Neurology. www.medinfo.ufl.edu

