

AN ORTHOTIC ODYSSEY

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President Shangali, distinguished guests, fellow ISPO members, I am delighted to be with you here in Vancouver for the 11th World Congress of ISPO.

The first thing that I need to do is to thank Harold for inviting me to make this presentation. As a life-long member of ISPO I can think of no other honour which would give me more pleasure.

Can I go now? No? Alright then, I'll begin

You will know that I have entitled my presentation "An Orthotic Odyssey". The classical scholars amongst you will be aware that the word "odyssey" is derived from the name of the Greek hero Odysseus whose "long and eventful journey" is described in Homer's epic tale of the same name.

The "odyssey" that I am referring to is the personal journey that I have made during my career as a bioengineer as I have explored the science and the practise of the field of orthotics. I should state at this point that my experience and thus the content of this presentation relates primarily to the subject of lower limb orthotics however I believe many of the topics I shall discuss are equally applicable to the field of orthotics generally.

I should also say that I believe that my personal journey closely parallels the evolutionary journey which the field of orthotics in general has made over the same time period.

My journey started in 1968 when as the newly appointed Research Bioengineer at Dundee Limb Fitting Centre I was dispatched by my director, the redoubtable George Murdoch, to N. America "to see what was happening in P&O."

During this visit I met a number of very kind and helpful people and I also learned many things, two of which are particularly relevant to this presentation: firstly,

"the absolutely essential role played by the subject of biomechanics in the recent significant developments in the field of prosthetics" (yes prosthetics), and secondly,

"that an orthosis did not need to look like this or this - but could actually look like this or this".

Returning to the UK I learned that a doctor in the midlands of England (Gordon Yates in Stoke-on-Trent) was already delivering this new technology.

After a brief visit to Stoke I quickly assembled the necessary equipment and materials (which a short time later led to my first meeting with Gordon Tullis of North Sea Plastics) established a clinic and started making and fitting plastic orthoses.

And that was when the first problem arose!

How to decide which patient should be fitted with which orthosis or indeed with any orthosis at all?

The expression that we adopted at this time for this process was of course "patient/orthosis matching".

This problem must seem rather absurd to those of you who have entered the field of orthotics more recently however I should explain to you that up until to this time virtually every manual or text book (and there were precious few) which I had consulted tended to classify patients by reference to their diagnosis and routinely used terms such as "drop foot brace" or "hemiplegic brace" to describe both the devices being supplied and their clinical application.

This approach had many flaws. As all of you will be aware there are many different causes of "drop foot" and "hemiplegic" patients present with a wide variety of functional problems. Clearly a more logical approach to the description of both the user and the device was required.

The solution which was eventually adopted for the first part of this problem was to be found in Jacqueline Perry's chapter on Pathologic Gait in the first edition of the Atlas of Orthotics – Biomechanical Principles and Applications in which she describes a model of normal physical activity and identifies the body tissues and physiological systems which contribute to each element of it.

Starting from this description she then proceeds to develop a classification of "functional loss" which completely eliminates the need for diagnostic labels.

The final step for us then was to develop a standard procedure to identify, describe and record each patient's individual defects and deficits.

The solution to the need to record this information was partially solved by adopting the elegant set of forms developed by the American Academy of Orthopaedic Surgeons which had recently been published in *Artificial Limbs* (1970),

At this point in my journey, the decision as to which design of orthosis would best “match” a particular need was largely “guesswork” since our understanding of the way in which orthoses worked was extremely limited. Nonetheless we had made an important step forward.

A second problem which we encountered at this time and had to react to was the realisation that for many patients supplying the first orthosis was just the first step in an on-going process. Patients change and as a consequence so do their needs, orthoses deteriorate and new materials and designs continually emerge.

And so it was necessary to design a complete “orthotic supply process” capable of continuously delivering all the elements of orthotic care in an individually tailored manner.

One of the most important and recurring issues which I have encountered during my journey is the subject of “Standards”.

Once a systematic orthotic supply process has been defined it becomes possible to develop and define what are now termed “Process Standards” which specify for each stage of a process precisely what should happen, who is responsible and where appropriate the time scale for it to be undertaken.

A second aspect of standards which I also first encountered at this time is the subject of standard terminology. As a first stage therefore in the process of more accurately describing the devices we were using we adopted the terminology developed by CPRD in Washington which classifies an orthosis by reference to the body segments that it encompasses. Such was the international popularity of this system that it was adopted as an international standard by ISO in 1989 as ISO 8549 – 3 Terms relating to external orthoses.

At this point in my journey it was becoming apparent to me that if we were to make any real progress with the process of patient/orthotic matching that it would be necessary to obtain a better understanding of how orthoses function, i.e. the biomechanics of orthotic function.

Now, I realise that just the mention of the word “biomechanics” is enough to send many people to sleep or even worse send them running for the exit. I

shall therefore try and make this part of my presentation as brief as possible - but it is important. Trust me – I'm an engineer!!

It was clear to everybody associated with orthotics that the function of any orthosis was primarily dependent on the properties of the components and the materials from which it was constructed and the manner in which they were assembled and shaped. However what is much less obvious to non-engineers is that it is as a consequence of the forces that occur at the areas of contact of the orthosis with the body, when it is donned and physical activities are undertaken, that these properties are imposed upon the user.

We needed therefore to learn more about these "orthosis/body forces". Using the technique termed "free body analysis" and applying the Laws of Motion propounded by Sir Isaac Newton the 18th century mathematician it is possible to "theoretically" establish what forces are required to achieve any desired orthotic function.

Thus for the example of an individual with a total loss of the power to plantarflex the ankle, the sites of the orthosis/body forces required to restore normal ankle function can be demonstrated to be under the heel, posterior at ankle level and anterior just below the knee.

All of the text books that I had previously consulted referred to the system of forces between an orthosis and the body segments it is attached to as the "three point force" or even worse the "three point pressure" effect of the orthosis. What our free body analyses quickly revealed was that the force systems required to achieve particular functions might consist of two, three or even four force components.

From that time onwards I therefore decided to refer to the effect of these force systems as "the direct effect" of the orthosis. Some of my bioengineering colleagues however prefer to use the expression "internal effect".

What our free body analyses also revealed, perhaps most importantly, was how we could optimise a particular design to minimise the magnitude of the forces and the pressure imposed on its user while still achieving the desired function. For example in the case just described the height of the shank element of the device (and hence the location of the anterior force) is the most critical feature.

One other important aspect of the biomechanical function of orthoses also required further study.

There is some debate as to whether it was Jimmy Saltiel from Israel or John Glancy from Indianapolis, U.S.A., who first described in the literature the use of a below knee brace to compensate for weakness of the knee extensors.

The basic biomechanical principle underlying this application is very simple. Walking wearing an orthosis with an orthotic ankle joint which prevents dorsiflexion, once foot flat is achieved, the centre of pressure of the ground reaction force moves forward such that its line of action passes in front of the anatomical knee joint centre creating an external knee extension moment.

The term which had been adopted for this type of action of an orthosis was the “ground reaction” or “floor reaction” effect.

The only biomechanical studies of this effect which I was aware were those of Lehmann et al at the University of Washington who demonstrated the importance of the angle at which dorsiflexion is stopped in achieving the desired effect.

For many years clinicians had been content to use this orthotic design when appropriate without recognising its wider implications for the design and function of lower limb orthoses.

To the best of my knowledge it was not until 1984 when my colleague Barry Meadows published his Ph.D. Thesis with the title “The influence of polypropylene ankle-foot orthoses on the gait of CP children” that the full significance of the ground reaction effect was demonstrated.

Summarised very briefly what Barry showed was that AFOs fitted to diplegic cerebral palsied children could not only reduce their tendency to hyperextend their knees during mid stance but could also encourage them to achieve hip extension during late stance thus enabling them to generate more normal push-off forces.

The explanation for these changes was demonstrated using biomechanical data obtained using a computerised gait analysis system.

The print-outs from the actual tests, which were performed in our Gait Analysis Laboratory in Dundee are shown here with on the left the “stick diagram” with superimposed force vectors for a cerebral palsied child walking without her AFOs and on the right the same data for the same child walking wearing her AFOs. Obviously there is a huge difference between these two diagrams, but what is the significance?

Let us look at just two instants in the gait cycle extracted from these diagrams.

Firstly considering mid-stance it may be seen how wearing the orthosis has moved the point of application of the ground reaction and its line action posteriorly thus reducing or even eliminating the abnormal knee extension moment which was present when walking unaided.

Secondly considering late stance it can also be seen how the realignment of the ground reaction force created when wearing the orthosis has reduced or eliminated the undesirable hip flexion moment which was present when walking unaided.

Just as with the earlier “theoretical” analyses of the direct biomechanical effects of orthoses perhaps one of the most important aspects of this study was the attention it drew to the need to optimise the function (or “tune” as it later became known) the orthoses by adjusting the cast angle and/or by using various designs of shoe sole and heel adaptations.

Because the terms “floor reaction” and “ground reaction” effect had become synonymous with the original Saltiel/Glancy AFO designs I decided to adopt the term “indirect (or external) effect” to refer to this type of action of an orthosis.

Suddenly we realised that we had been using the “indirect effect” in all sorts of orthotic applications ranging from very simple shoe adaptations for an unstable subtalar joint through knee-ankle-foot orthoses employing off-set orthotic knee joints (such as the UCLA design), all the way up to complex designs of HKAFOs for paraplegic patients..

This latter area of orthotic design and application is also of particular interest because of the manner in which the power of the unimpaired upper limbs is harnessed to facilitate the orthotic function.

I first visited Toronto in 1971 to meet Wally Motloch and saw then his first experimental designs of reciprocating gait orthoses fitted to spina bifida children. To be honest at the time I simply could not understand why they worked. In fact it was not until many years later when I was preparing a lecture on HKAFO biomechanics and read Richard Major’s paper on the dynamics of walking using the Hip Guidance Orthosis that I finally fully recognised the mechanisms which were operating in the early Toronto designs, the HGO and the later reciprocating design of HKAFO developed by Roy Douglas at Louisiana State University known as the RGO.

I am going to beg your forbearance while I briefly explain what is actually going on in these orthoses.

All of these designs of orthoses incorporate knee locks to maintain the user's knees in full extension. The hip joints of the HGO are free within a preset range while those of the RGO, like the Toronto designs, are linked to one another so that they are obliged to move in a reciprocal manner.

Free standing is achieved by virtue of the knee extension moment created by the three component direct force system generated by the knee locks while maintaining a hyperextended position of the hips using the walking aids (usually crutches) which all users of these systems must use.

But how does the user who has no hip joint muscle power achieve reciprocal gait? The answer lies in the manner in which the walking aids are employed and once again may be explained using Newton's laws.

Let's look at the mechanisms which are involved in achieving just one step.

Firstly the body must be tilted towards the leading leg to achieve clearance of the trailing leg. This action is achieved using elbow extension to push downwards with the contralateral walking aid.

Secondly the ipsilateral shoulder joint is extended. This action creates a horizontal posteriorly directed force between the crutch tip and the ground which must (applying Newton's 3rd Law) result in an equal and opposite (anteriorly directed) force by the ground on the crutch.

Equilibrium (as defined in Newton's 1st Law) requires that an identical pair of horizontal forces are generated between the ground and the supporting foot (which is already supporting body weight).

The combination of the horizontal and the vertical forces acting upon the supporting foot creates a single force whose line of action passes behind the hip joint centre creating an extension moment.

This enables the user to move forward over the supporting limb.

In summary, both of these orthotic designs utilise extension of the contralateral elbow to achieve swing limb foot clearance, a direct force system to maintain stance limb knee stability and the power of the unimpaired shoulder joints to create an indirect force system causing hip joint extension

Owing to time constraints I will not today (you will be relieved to learn) describe the mechanisms which act to cause the trailing leg to swing forward.

In 1993 I was proud to be a co-editor of what I believe was the first attempt to bring together all the current knowledge on the biomechanics of orthotics in a single volume. Several of the contributors to this text are present in this

audience today. The Biomechanical Basis of Orthotic Management as it was entitled is now sadly out of print however it remains one of the principal reference text on this topic in many orthotic schools worldwide.

Just a few years later, the late Andre Bahler, an orthotist of some distinction, published his excellent text in the German language which covers a similar range of topics.

Several other significant developments have occurred during more recent years which have added to the sophistication of the supply processes which I have already described.

For example, returning to the topic of standards, I was privileged to be the Convener of the ISO Working Group responsible for drafting ISO 8551 which was finally published in 2003. This standard attempts to formalise the process of describing the user (previously described) and then proceeds to describe a method and a terminology for defining firstly the "clinical objectives" of orthotic treatment and secondly " the functional requirements " of the orthosis to achieve them.

Further details of this standard and all the other existing ISO orthotic terminology standards are contained in the first chapter of the newly published Atlas of Orthoses and Assistive Devices.

Our understanding of orthotic biomechanics of course also continues to grow.

Two comparatively recent developments are worthy of mention. I was particularly excited to listen to the paper presented by Sakamoto et al at the last ISPO Congress in Hong Kong which provided for the first time experimental confirmation of the theoretical predictions regarding the nature of the direct force systems occurring in some designs of AFO which we have been relying upon for the past 30 years.

Secondly, Elaine Owen's publications on the subject of tuning AFO-footwear combinations for children with cerebral palsy drew to our attention to the need to recognise that the cast angle selected for an AFO in order to create a particular external or indirect effect will have a profound direct effect upon the function of the two-joint gastrocnemius at the knee joint.

And so with our comprehensive patient assessment protocols and our collected orthotic biomechanical theory do we have all the tools required to successfully conduct the orthotic prescription process?

Well, perhaps yes, when considering some of the more straightforward orthotic applications which are designed to achieve a single clear objective which is unlikely to change unless to become unnecessary.

It is ironic that almost the first step we took in the development of our systematic assessment process was to eliminate the use of diagnostic labels and rely upon a purely functional description of the patient's impairments.

Today however with our vastly increased experience and understanding of orthotic practise we realise that when considering the orthotic management of some categories of patient including more complex congenital and acquired conditions, where the clinical objectives are constantly changing, that there are other factors which also require consideration.

These include for example, the developmental status of the patient (if a child), the stage of the disorder (if progressive) and the implications and effects of other concurrent treatments.

So how have we attempted to collate and make generally available existing knowledge regarding these matters?

The approach adopted by ISPO which I am delighted to have played an active role in over the past ten years is the "consensus conference", firstly in 1995 on the topic of the Orthotic Management of Cerebral Palsy, secondly in 1999 on the Management of Poliomyelitis and most recently in 2003 on the Orthotic Management of Stroke Patients..

Expressed rather simply, these events involve bringing together an invited group of experts from all the relevant disciplines, who are required to review all the published evidence of the outcomes of the various treatments including orthotics and arrive at recommendations concerning which treatments should be employed for which patients and at what times.

An alternative method of arriving at a consensus regarding these issues which depends more on "clinical experience" rather than "published evidence" has been applied by clinicians in the Netherlands to the topic of orthotic prescription as described recently in P&O International.

At some point in this presentation I need to mention "people". During my journey I have met many exceptional people all of whom have informed me in one way or another and many of whom have become close friends.

There are far too many to mention individually today, however hopefully they will find themselves somewhere on these two slides. Without their

cooperation and friendship my journey would have been much less memorable.

At the beginning of this presentation you will perhaps remember I referred to my recognition of the vital role played by biomechanics in the important developments in the field of prosthetics during the first two post war decades. You will have deduced from my description of my experiences during my journey during the succeeding four decades that I am even more passionate about the importance of and the need for a good understanding of biomechanics for the successful practise of orthotics.

My professional career has focussed primarily on service provision and research rather than on education, however I have seized upon with pleasure every opportunity, as a Visiting Lecturer at the University of Strathclyde and within ISPO both at congresses such as this and within the Society's short course programme to share both my knowledge and my passion. In recent years I have been particularly privileged to have had the opportunity of contributing on this topic in the B.Sc. Prosthetics/Orthotics programme at the Tanzanian Training Centre for Orthopaedic Technology, of which our President is the Director.

My journey is approaching its end. However the "journey" which the field of orthotics has undertaken since I first came upon it continues. So what do I consider will be the most likely and the most significant avenues it will follow. I have chosen three to mention.

My journey started with the introduction of thermoplastics to the field of orthotics. I have no doubt that the chemists and the materials scientists will continue to produce ever more convenient materials and manufacturing processes which will afford new opportunities for designers and which will make the orthotist's task easier and more consistent – but I doubt if any will have the same impact on the field as that first "plastic revolution" back in the sixties.

I have said very little in this presentation about the joints (or articulations as ISO would have us term them) which we incorporate in our orthoses. You will however remember that I stated that it is the properties of the components (including the joints) which will determine the type of control which an orthosis can exert. Importantly it is the design of the joints which determines both when (in the gait cycle) this control is exerted and the magnitude of the controlling forces. A joint which limits the range of motion of an anatomical joint will have a very different effect from one which is locked.

The range of types of joints available has expanded dramatically during the past 20 years stimulated to a degree by the demand for components which are compatible with thermoplastic interface components.

In spite of this activity the vast majority of the orthotic designs that I am familiar with which are in common use today are what I would describe as “passive”, that is, their biomechanical properties are fixed at the time of manufacture and fitting and are unvarying .I believe that there are many situations where an “active” design of orthosis would permit much more effective orthotic treatment.

The “ buzz word” for this type of design is the “intelligent “ orthosis meaning an orthosis whose properties although still set at the time of manufacture can vary to suit differing circumstances during its use.

The most obvious example of this concept which has already challenged designers in several countries in recent years are the so called ”stance control orthoses or SCOs ” designed for use by patients with severe quadriceps weakness which provide knee stability when loaded by body weight, such as during stance, but which flex freely when unloaded as is the case during swing. I hope and believe that we will see many more examples of active or intelligent orthotic designs before long.

My third and last thought for the future is more of a plea than a forecast and I have touched upon it when I mentioned consensus conferences – that is outcomes.

In 1974 at the first ISPO World Congress in Montreux I presented a paper describing experience in the use of AFOs with a range of patient categories which included data obtained using a very simple form to record selected features of the users’ gait patterns before and after orthotic supply.

The gait observations were made visually and there was no statistical treatment of the data to assess its significance. Very crude by modern standards.

Two years ago the library of the P&O school at the University of Strathclyde conducted a search for all publications on the topic of prosthetic or orthotic treatment using the RECAL database and a list of search terms which included audit, evaluation, follow-up, outcome, measure/measurement and analyse/analysis. The search found over 500 references however closer examination identified only 25 papers on orthotic treatment which employed either qualitative or quantitative measurement methods. Only one publication met the criteria for Level of Evidence (LoE) 1 (as defined by Greenhalgh), one

the criteria for LoE 2 and 15 the criteria for LoE 3 or 4 which are cohort studies or case control studies respectively. Now I am sure that a similar search conducted today would uncover many more publications however I would also suggest that progress in this area of orthotic activity during the 30 years since Montreux has been unacceptably slow.

There are many reasons why this must change. The field of medicine generally has long accepted the need to measure the effects of treatment and thus provide justification for its implementation. The field of prosthetics has fully embraced this philosophy as evidenced by the scientific programme for this congress. The people who pay for orthotic treatment are increasingly demanding proof that their money is being spent in an appropriate manner. Finally, and for me most importantly for the continuing evolution and development of any field it is absolutely essential to know what techniques are effective and if possible understand why.

Ladies and gentlemen, it has been a privilege to address you on a topic which has fascinated me almost all of my working life. I must apologise for the fact that it has involved quite a bit of time travel since not all of the events I have described have been in strictly chronological order. I am not sure that Homer would have approved.

Thank you for your attention.

