THE KNUD JANSEN LECTURE
KOBE 1989

Technological choices in prosthetics and orthotics for developing countries

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Introduction
I am thankful to the President and the Executive Board of ISPO for asking me to deliver this prestigious lecture.
Knud Jansen was not only a humanist, as all good and wise doctors are, but he had an extraordinary ability to go directly to the heart of the matter. I sensed this when Prof. George Murdoch advised me to go to Copenhagen in 1971 to show him my work on a prosthetic footpiece. Dr. Jansen made me realize, in his characteristic gentle manner, that I should look beyond the product which I was viewing as a rather culture-specific innovation and understand the process by which this design was arrived at. "Sensitivity to user reaction is a more valuable tool", he said, "for designing appliances in developing countries, than an expensive laboratory back up." This has altered my perceptions very significantly. To him and to his friends George Murdoch and John Hughes, I owe a special vote of thanks for providing me with a sense of direction.
The reason which has prompted me to take up the subject of technological choices is because of the feverish activity which has been going on in the developing world, ever since the United Nations declared 1981 as the "Year of the Handicapped". Surveys of the handicapped have since been conducted and for the first time our governments have become aware of their staggering numbers. With 80% of our population living in abject poverty in remote rural and often inaccessible areas, the logistics of producing appliances for them and then "reaching the unreached" is truly mind boggling.

Such surveys are always accompanied with inevitable promises to the people which convert what perhaps was a "felt but unsatisfied" need of the disabled to a "vocal demand" by them for prosthetic and orthotic aids.
Brainy committees are deliberating on this problem and Technology Missions are being set up to speed our entry into the 21st Century following the W.H.O. slogan of "Health for All by 2000 A.D.". Targets have to be achieved. We need more targeted research, more mission-oriented science. This is said to be the new drift. Suddenly the pressure is on and since there is little time to waste, it is considered prudent to buy technology packages from the west. There is no point in rediscovering the wheel.
I sense serious trouble when we initiate such a "top-down" move. Such moves require a much greater store of usable information, with coherence and connectedness, than actually exists. We have to face, in whatever discomfort, the real possibility that our level of insight into the actual needs of our disabled masses is far from complete. The developing world has a stratified social structure, with a top ten percent of the urban elite and a bottom ninety percent of our rural and urban poor. The top ten percent, many of whom have imbibed the life style,

the culture and the value system of the west, want that their country too should have the same kind of appliances as are available in the advanced countries. They are the decision-makers and exercise control over what may be viewed as the "technology filter", through which the needs of society have to pass to create a "technology demand". The bottom ninety percent have no voice and they have never really mattered. In a situation like this, it is almost inevitable that the policy decisions would tilt heavily in favour of the urban affluent and opt for expensive technology.

Realizing this, there is emerging another viewpoint which has taken up the cause of the rural poor. Taking into consideration our resource crunch, the pendulum is made to swing to another extreme. Primitive and traditional technology is romanticized and some simplistic solutions are being advocated by this group. I must confess I have great respect for traditional technologies which are rooted in our culture. These have evolved through a long process of natural selection and therefore they must not be ignored as sources of innovations. But while these traditional technologies offered optimal solutions for the challenges of the past, they are clearly sub-optimal and inadequate today because of changed expectations, resource availability, materials and circumstances.

It has also to be understood that technology for the poor cannot either be trivial or second classy because it invariably poses the tough challenge of having to be "zero-cost". Hassan Fathy's work on "Architecture for the Poor" is an excellent example of the kind of effort and thinking which is needed for this purpose, and I would strongly recommend his book from which valuable lessons can be learnt.

What I find missing from this debate, however, is that a distinction is not being made between science and technology. We are confusing expensive gadgetry with good science. This often is not so. It requires some very sophisticated thinking to arrive at a simple solution. It is much easier to work out a complicated and expensive solution. Indeed, whenever one encounters an expensive and complicated technology, one can take it that the basic issues have not been understood. Expensive gadgetry often possesses impressive "Symbolic Value" as opposed to "Use Value". What we want is more, and not less, science in the developing world.

There is one problem with science, however. It relies essentially on objectivity and quantitative measurements. In medical practice, the scientific method often decomposes the patient as a person and converts him to a set of laboratory findings.

This shadow patient, reconstructed from the results of laboratory tests, then acquires a reality and autonomy of his own. It is with this shadow patient that our scientists are concerned. The rest, that is the patient's personal realities, are seen as variables which induce compromises with the science (as opposed to the art) of medicine. They are not seen as variables having an intrinsic scientific status. Indeed, as Tariq Banuri has pointed out, a basic postulate of modernization is the inherent superiority of the impersonal over the personal. The patient's voice, his language of suffering, is treated as a noise, somewhat like the "signal-noise ratio" on a radar screen. The cold reason of the medical scientist treats this noise as a nuisance and attempts to smother it to be able to read the signal properly.

We must realize that designing prosthetic and' orthotic aids cannot be an impersonal, biomechanical solution of a locomotor deficiency and dysfunction. It is a very complex issue because we are dealing with live human beings with their varied life styles and cultures which have evolved through centuries of adaptation. Our technological solutions must respect these traditions to permit the users to integrate into their environment. Science should be utilized to simplify the solutions and the technology should not breed inequity. Above all, a feeling of empathy and a sensitivity to the user response must characterize our work.

To be able to learn about the 'felt needs' of our rural masses, we have to leave our institutional hideouts and mix with them and methodically study their ways of living and thinking. One would then realize that while they are poor and illiterate, they are not irrational. In fact, the poorer they are the more does their survival depend on rationality, i.e. upon a proper evaluation of costs and benefits. Since we are mere beginners in such an attempt, there necessarily has to be an intense back and forth interaction between the laboratory and the field. The first generation of our prosthetic and orthotic aids would be full of mistakes but if we are tolerant of the feedback, the subsequent attempts would be increasingly successful.

This kind of approach is necessarily more time-consuming, but in the long haul, it is more likely that our solutions would turn out to be more appropriate and durable. A lot of flexibility for modifications/corrections should be available and this would only be possible in small scale efforts. A centralized, top-down, capital-intensive, administered technology can never have the manoeuverability to make such mid-course corrections.

Let me illustrate the foregoing by narrating my own experience in designing an appropriate lower limb prosthesis for our people.

When we first started providing lower limb prostheses to our amputees, the majority of whom belonged to the lower income groups, we used designs which we had learnt from the west. I thought we were making a decent attempt, even though our limbs looked like "blurred Xerox copies" of those available in the advanced countries. It came as a surprise, however, when I started encountering many of these amputees reverting to their crutches. I started closely questioning them about the reasons for this rejection. It soon became obvious that a design which was appropriate in the shoe-wearing, chair-sitting culture of the colder countries of Europe or North America was quite inappropriate for the barefoot walking, floor-sitting culture of the warmer countries.

Two cultures — floor sitting vs chair sitting

In the cold climate of Europe or North America, the feet have to be protected from cold by using warm socks and closed shoes. Chairs are used to move away from the cold floor and so a table becomes a work surface. People walk on paved streets and level floors and the foot is not often required to adapt to uneven surf ace.

On the other hand, in the warm climates of the developing countries, closed shoes are uncomfortable and most people walk barefoot or else in open well-ventilated footwear, often on the rugged terrain of our countryside where suppleness of feet is a vital attribute to adapt to uneven surfaces. Furniture is not used. The floor is used for sitting, sleeping, eating, working and worshiping. Shoes, if worn are removed when entering homes or places of worship to prevent dirtying the floor.

It is important to distinguish between chair-sitting and floor-sitting cultures because there are important design implications involved.

The western designed limb

The western designed footpiece is meant to be used within a shoe and so its shape conforms to a shoe last to provide an easy foot entry and it need have no resemblance to a human foot. The shoe not only hides its odd appearance but also protects it from damage. A shoe, in other words, becomes an integral part of the limb design. Take the shoe off and you cannot use the limb.

One can then easily appreciate how such a simple demand can pose major problems when closed shoes are not only uncomfortable in our hot climate but because they have to be repeatedly removed in a floor-sitting culture.

Not only this. We squat on the floor and this requires a range of mobility in the knee and ankle which is not available in a western limb. The SACH foot, with its solid keel does not

allow any dorsiflexion and so the patient cannot squat on the floor.
An attempt to sit cross-legged on the floor presses the stiff foot piece along its outer border, which in turn forces the shank to twist, causing an unbearable pressure on the stump-socket interface. To be able to work sitting in a cross-legged position, the limb is usually taken off and then crutches have to be used to move around while at work. A farmer ploughing his field in traditional ways, cannot afford to wear a pair of Oxford shoes!
And so, unless the amputee changes his lift-style into a shoe-wearing, chair-sitting culture, he finds it simpler to revert to crutches.

Design criteria for a prosthetic footpiece
Based on the foregoing, it was decided to redesign the foot-piece by listing out a set of desirable criteria. It should not require a shoe to protect and hide it. So it should look like a normal foot and be made of a material which is not only flexible but also tough, abrasion and tear resistant and waterproof. The internal design should provide adequate mobility to enable sitting on the floor and walking on an uneven terrain where the foot is required to adapt to the rugged terrain of our country-side. And yet the foot should offer a stable support while walking.
I worked out the theoretical constructs, the main feature of which was to get rid of the solid keel of a SACH foot.

Reaction of formally trained prosthetists
The formally trained prosthetists working with me, were baffled when faced with such a design demand. In a way this was inevitable. For who are these people who man our formal limb-fitting centres? These are drawn from our urban middle classes where there is no culture of manual work or innovations. They were admitted to the training schools because they had learnt English language, which is a prerequisite to their admission. Reared in an urban environment they do not understand rural problems and cannot communicate with the rural disabled in their language, dialect and idiom. Their value system has mercenary overtones and they show little empathy when their patients point out their difficulties. They can use a technical jargon, drawn from the NYU curriculum which forms the basis of their training, and glibly talk of centre of gravity, kinetics and kinematics, shifting knee axis and the like, without really grasping the concepts involved. They have little capacity to innovate, and become helpless when a particular tool or material is not available. They are so conditioned by their system of education that any deviation from orthodox designs is sacrilege to them.

Traditional craftsmen
Finding that I could make no headway with them, I was forced to turn to our traditional craftsmen. They are often illiterate but they are the real possessors of manual skills in our countries. They have tremendous capacity to innovate and they know all about locally available materials. One, of course, has to learn to treat them with respect and communicate with them in a different manner. They feel ill at ease with drawings or illustrations but show them a 3-dimensional model and they would amaze you with the ease with which they can reproduce it using their own technology, tools and materials. So, with the help of our local craftsmen, an aluminium die was produced in the backyard of our hospital, using traditional sand casting methods to reproduce the shape of a human foot at a fraction of the cost a professional die making firm would ask. It was decided to use wood and microcellular rubber which is freely available in almost all countries for open sandals, glue the sheets together and

then encapsulate these inserts with a solid
rubber elastomer readily available for putting new treads on worn out tyres, mould the piece in the die and vulcanize it in our hospital autoclave. People everywhere know how to vulcanize rubber because of an extensive trade in retreading worn out automobile tyres.
I would not describe the evolution of this design, which went through several stages, with a constant feedback from our amputees till we arrived at a solution, which was a radical departure from a SACH foot. The solid keel was done away with. Instead, a universal joint was made available in the large microcellular hindfoot block, with freedom of movements in all directions.
The product of this simple and inexpensive technology was not only field tested but also subject to careful scrutiny in the laboratory of our engineering college, drawing up load deflection curves and testing for strength in a universal testing machine.
Need for alterations kept on arising and we were ready to respond to them. For instance, we had not foreseen the consequences of repeated flexions and soon the amputees started returning with the external shell cracking open and the various inserts popping out. To guard against such disastrous failures we started binding the three main structural blocks with rubberized tyrecord in a way that the mobility of the footpiece was not adversely affected. This greatly increased the strength of the footpiece and we obtained a breaking-load figure of 6 tons and a footpiece which could last for 3-5 years, under tough field conditions in village farms.
A second major change was introduced when a study of our broken footpieces showed a consistent pattern of cracks being always located at the ankle region. This could be readily explained because all the mobility resided in the hindfort region in the zone between the two wooden blocks. This is where all the stress concentration was located. Then we replaced the wooden forefoot block by another MCR block, adequately stiffened with extra tyre cord to prevent it from buckling in the late stance phase of the walking cycle. The stress distribution was thus dispersed over a much larger area, and we got an extra bonus of pronation and supination of the forefoot. The forefoot could now independently adapt to uneven surfaces and the transmission of groundreactions to the stump-socket interface was much more effectively dampened.

Transverse rotation

A rotator device, advocated by Radcliffe, is not needed because adequate transverse rotation of the shank on the footpiccc is already built in to this design resulting in a more comfortable stump-socket interface.
Absorption of ground reactions has a higher priority when walking over a rough terrain than the energy-release kind of athletic footpieces which are getting popular. An analogy with the rubber bearings advised for earthquake proof high rise buildings which provide a "base isolation" and detune the building from the whiplash effect which can shake the top storeys to virtual destruction seems to me to be appropriate.

Jaipur foot

One can now match the list of our earlier objectives to what has been achieved. The foot fairly closely resembles a normal foot, and it is often difficult to identify the amputated side. In fact, women often adorn their feet in a manner which has even fooled me.
The amputee can squat and one can witness the angle which the footpiece can make with the leg. There are amputees employed in our workshop who sit cross-legged on the floor and

work for the whole day without the need for taking their limbs off.
Villagers walk comfortably on a rugged terrain because of the adaptability of our footpiece.
The limb is waterproof and many amputees work in their farms, wading through water and mud. Drawing water for irrigation from a well is a heavy duty job and yet these amputees perform such work like an able-bodied individual. Rickshaw pulling is an urban vocation chosen by many poor amputees. They can even climb trees and in rural areas this is a valuable asset. Witness the way the footpiece can grip the trunk and adapt to its contours.
It would be appreciated that such activities allow the patients to continue to stay in their villages, with their own families and friends. It is no longer necessary for them to migrate to an urban area, and plead to the Social Welfare Ministry for a sedentary occupation in an alien setting. This is what "true rehabilitation" ought to mean.
All this was achieved, at a minimal cost, in the backyard of our hospital. I want to emphasize that this small scale effort allowed us a lot of room for flexibility in changing the design based on feed back from patients. Had the design been worked out on paper and then handed over to a manufacturer, it would have been very difficult to persuade them to make any changes.

Choice of materials — aluminium limb

For the socket and shank of our BK limb, we opted for aluminium as a suitable material. Most of my colleagues react adversely to this choice. "The modern world is moving towards polymers and composites and you are moving back to metals!" they comment. There are some good reasons why 1 have preferred aluminium — at least for BK limbs. We have skilled artisans in our country who can shape metal sheets with such ease and deftness that it takes one by surprise. A statue of a poor, emaciated amputee, which stands before our Rehabilitation Centre, was made by one of our craftsmen with aluminium sheets beaten into shape without any casting. For people who can produce such a stunning piece of art, shaping an aluminium limb is child's play.
Visitors from abroad gape with amazement when, within 45 minutes, from start to finish, a BK trial limb is fitted. The tools for this work are simple; no plaster moulds are needed. These workers have been taught the principles of why we deform sockets to exploit the pressure tolerant areas and relieve the pressure sensitive bony prominences and scars. Alignment principles have been taught and adjustments are effected by an open wedge technique familiar to most orthopaedic surgeons. The limb is shaped and fitted directly on to the amputee who becomes an active participant in the entire proceeding, guiding and informing the limb maker about the accuracy of the fit. The sensory feedback from a live stump is perhaps more accurate than a blanching of skin in a transparent check socket.
The live human interaction between the amputee and the limb maker is a marvelous thing to watch. There is empathy and understanding between the two and a lot of feeling goes into this work.
I have chosen aluminium because it is available to us, easy to work with, light and strong and does not rust. Pressure points can be easily lifted off with the tap of a mallet. Use modern FRP and you get into a much more expensive system where such manoeuverability is just not available after the resin is cured. It is this simplification of the technology which enabled us to increase our turnover of work from one limb a week in 1975 to ten limbs a day in 1982.

Socket design

There has been criticism that we are not providing total contact sockets. It may be noted, however, that our sockets are not the old fashioned "plug fits" and there is a very intimate contact between the skin-socket interface with little loss of energy when the stump moves the limb. Unlike in the west, 80% of our amputees lose their limbs because of trauma or infection, are young and have a normal vascular tree. An open-ended socket is preferred because it is cooler and more comfortable. A suction socket, for instance, is usually not accepted for this reason. An initial selection can always weed out the dysvascular, the diabetic, or the anaesthetic stump in leprosy for whom every care is taken to provide a safer socket system. In over 20,000 amputees, we have only rarely been required to change the socket because of distal oedema.

Using this technique, we can offer a quicker delivery system at a lower cost than almost any alternative that I know of.

Materials should be chosen not only for their properties but also on the basis of availability and familiarity. Whether one opts for metal, wood, FRP or thermoplastics, is less important. The basic principles of socket fitting and alignment, I am convinced, are far more important.

Reaction of urban amputees

While our rural amputees are happy with our footpiece, our affluent urban amputees complain that they cannot insert this easily in fashionable shoes. It has to be understood that the barefoot population have a broader foot and this has been our target group. It is simple enough to have an external shape of a SACH foot with an internal design of a Jaipur Foot. We have prepared some, and with a detachable heel too, which preserves the alignment when shoes are removed indoors.

I am aware of all the shortcomings in our footpiece. Its cosmetic appearance needs to be refined, it should be lighter in weight and there should be quality control and product assurance, something difficult to achieve in a very labour intensive technology. We are currently making these attempts, both by trying to update our rubber formulations and production technology, and also to substitute rubber with polyurethane.

High technology

We have been facing one problem with exotic materials like polyurethanes. This requires a much higher capital investment and the operating conditions for manufacture are extremely critical. There is little margin of error permitted otherwise a catastrophic failure would occur. Rubber, on the other hand, may not be as elegant but is much less likely to fail.

An analogy from agriculture on the debate between "traditional" versus "high yielding varieties" of wheat may not be out of place. Let us not forget the nursery rhyme — "when she was good, she was very very good, but when she was bad, she was horrid.

We should not lose sight of the "worst case scenario" and only dream of the "best case scenario", when evaluating costs and benefits. It is also important to resist the temptation of yielding to an applause from the west, and in the process, forget our rural masses, for whom this work was taken up in the first instance.

Appliances for poliomyelitis

Likewise, different alternative approaches may be used for polio patients.

Metal calipers for stabilizing flail limbs in poliomyelitis have been used for decades. Patients dislike them for obvious reasons. The drop-out rate is disturbing and most children prefer to limp around without them.

With the advent of newer materials such as plastics, one could break away from the tyranny imposed by metals and use fresh geometries of design. I have used the "Floor-Reaction" principle for stabilizing an unstable knee with quadriceps paralysis with an 85% acceptance rate in over 600 cases. Using space-age materials like carbon fibre composites, a much lighter and effective appliance can be used. I am fully aware of the lack of availability of such materials in developing countries but this venture has been a great education, teaching me much more, not only about new design principles and new ways of looking at paralysed limbs, but also to have a feel for the child's feelings, difficulties and preferences. I am already moving away from FRP, which bring their own problems, to thermoplastics such as polypropylene which seem to offer many advantages. Our illiterate but skilled workers can now prepare these appliances with ease and have shown what a powerful tool demystification of professional knowledge can be, provided one has a belief in the intrinsic, native intelligence of people.

Such plastic appliances, however, are necessarily custom made and require great care and precision. Mass scale use is not feasible and heat retention over sweating skin is a problem still awaiting a solution. Components of metal calipers, on the other hand, can be mass produced and the design allows much better ventilation.

Realizing that any single village would seldom have more than half a dozen polio children, I have experimented with a simple design borrowed from Huckstep in Uganda, improved on its wooden clog to provide a better roll characteristic and then utilized the village carpenter, cobbler and blacksmith, to prepare calipers with their own tools, materials and technology, by showing them the 3-dimensional samples I have alluded to earlier. The results have been astounding. Here then, is another alternative approach to utilize a readily available manpower in providing neighbourhood facilities to a village child on his doorstep. Our centralized authorities, overwhelmed by the staggering numbers of millions of such cases, are still struggling with their customary managerial approach with a track record which makes one rather sceptical of a successful outcome.

I know how our professionals react to such proposals which they find outrageous. On the one hand, such a strategy may provide inadequate aids, on the other hand, adequate technologies are inaccessible. Adhering to the idea of providing only the best usually means that 90% of our disabled population have to go without any aid whatsoever.

All the three alternatives — viz. mass produced caliper components fitted locally, simplifying existing design to utilize rural craftsmen for a more effective delivery system and to pursue R&D activities making use of new materials and new designs and field test them — can exist simultaneously. The costs and benefits of each will have to be worked out but in all this, let us not forget the user who would usually belong to the group of rural poor.

The constraints of time prevent me from multiplying such examples endlessly.

The main point I have tried to make is that in a dual society such as ours, and this is true of all developing countries, we are constantly running into a Hobson's choice. The technologies and designs evolved in the west are preferred by our rich urban elite and they really constitute the market forces which influence our decision makers and western trained professionals. The poor are outside the market forces and have no voice. Modern technologies are inaccessible to them. To permit the poor to escape from this dilemma scientists and technologists must generate new options, each more effective than the traditional, and more accessible than the modern. Ideally, the options should constitute a hierarchy of technologies with upward compatibility. Then, with rising incomes, the poor can climb from a cheaper, less cost-effective option to a costlier, more cost effective option. Only in such a situation will the people have genuine choices. Thus, the role of scientists and technologists is to be option-generators and choice-wideners.

People who control decision-making in our country are understandably in a hurry. They overlook that a more appropriate and equitable generation of technology involves a "learning curve". During the inital part of this learning curve, there has to be intense back-and-forth interaction between the laboratory and the field. The feedback from users in the field must lead to modifications and improvements of the product/process. This modified/improved product/process needs further "test marketing" in the field. As a result of this interplay between technology generation and dissemination, and between technologists and potential consumers of the technology, the penetration of the "market" is necessarily very slow during this phase. Only later, our learning curve shows a steep climb.

All these points are generally ignored when technology dissemination is planned and implemented. There is a general tendency for technology generation and technology dissemination to be thought of as two distinct non-overlapping sequential stages with the generation ending when the dissemination begins, and the generators "washing their hands of" the technology dissemination process.

However idealistic and romantic it may appear, my conviction is that the technologists must approach such work with empathy and affection for the people. Otherwise, they tend to be afraid of the people and hide behind their institutional walls. The poor are far more understanding of our failures than the so called educated, as long as they know that we are genuinely interested in them and not using them for populist slogans or advancing our own career structure. Science and technology ought not to be "value-free" and would stand to gain from these feelings of empathy and affection. Without this value-system, it tends to become amoral, unjust and violent.

A lot of hard and painstaking work lies ahead of us. The problems facing us are open-ended. This is why I am worried about a 'top-down' managerial approach which, some people think, will quickly solve our problems. Bernard Shaw's approval of "the inevitability of gradualness" carries for me a lot of wisdom.