Bertil ALDMAN Award Lecture

IRCOBI – Past, Present and Future

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I am not going to give a state of the art lecture on some specific aspect of biomechanical research. Instead I want to give you my view of IRCOBI as it has evolved with a view to what future directions it might take. To invite one of the two surviving members of the original IRCOBI Council to give this lecture is to risk an overdose of rampant nostalgia. I will indeed subject you all to a moderate dose. Not, I hope for self-indulgent reasons, but because the past can sometimes help to illuminate the future. But also, many of you here today have been contributing to these IRCOBI conferences for a good number of years, and have taken part in the evolution of IRCOBI to where it is at present. But what is of more interest is the future of the subject and how IRCOBI can best adapt to the changing world.

It has been pointed out to me that in fact the first annual IRCOBI conference took place in 1973. Hence the 40th conference occurred last year. However, if you look for the 1983 proceedings you will see that it is in fact the STAPP conference proceedings for that year. It does include some manuscripts provided by IRCOBI but the conference was almost totally run by SAE, held in San Diego and attended by very few people from Europe. That hardly qualifies it as a genuine IRCOBI conference.

And to be legalistic of course, IRCOBI did not officially exist until June 1975 when it was registered and officially recognised in France in Le Journal Officiel de la Republique Francaise. So we can celebrate another 40th anniversary next year.

THE ORIGINS OF IRCOBI

The origins of crashworthiness were in aviation safety with Hugh De Haven, a New Yorker who in 1917 was training as a pilot in the Royal Flying Corps of Canada when he had a mid-air collision. The other pilot died but De Haven survived albeit with ruptures of the pancreas, liver and gall bladder as well as two broken legs. He reasoned that he survived because he was using a seat belt and the cockpit remained largely intact. He also realised that his abdominal injuries arose from the hostile design of the buckle of the lap belt which was located in the middle of the abdomen. Amongst many other achievements he produced a still relevant study, published in 1942, which should be in the library of every biomechanical engineer – “Mechanical Analysis of Survival in Falls from Heights of Fifty to One Hundred and Fifty Feet” [1]. De Haven measured the deceleration distances for people who survived falls from great heights and landed on relatively soft ground, the sheet metal of car roofs or banks of snow. He thus calculated average whole body decelerations and showed that survival, in some instances with minimal injury, occurred when decelerations were in the range of 120g to 200g.

In 1953 De Haven set up the Automobile Crash Injury Research programme at Cornell University [2]. That programme persuaded a sample of police forces across the country to collect more detailed crash related information than they normally did. That was merged with injury information from hospitals and the people involved. Amongst other things ACIR produced an injury severity scale: Minor, Moderate, Severe, Serious, Critical, Fatal (with four categories). That scale subsequently formed the basis of the first Abbreviated Injury Scale in 1971[3].

Thus, the application of crashworthiness principles applied to cars was born. Adoption of these scientific principles however, took a long time. De Haven and John Paul Stapp produced the first data points for future human tolerance curves but institutional opposition was enormous. The first breakthrough occurred with the U.S. National Traffic and Motor Vehicle Safety Acts in 1966 which empowered the Federal Government to set standards for vehicle safety. The FMVSS 200 series of standards were devised by the National Highway Safety Bureau, the forerunner of NHTSA, headed by William Haddon. Many of those initial standards merely reflected what was the best practice at the time, with little biomechanical input. Thus, for example, steering column intrusion was limited in the 30 mph flat barrier test to 127 mm (5 inches) rearward but no limit was placed on upward motion. Seat belt retractor vehicle sensitivity locking levels were specified to be below 0.7g, subsequent crash investigations and testing showed that a much lower level was to be preferred. Most of the federal standards became requirements on new cars sold in the United States between 1968 and 1972. The consequences of those initial standards reverberated around the world because the North American market was huge and also because the big three manufacturers in Detroit had a major presence in Europe.

The Organisation for Economic Co-operation and Development (OECD in Paris), the European Conference of Ministers of Transport, the European Economic Community (EEC in Brussels) and the Economic Commission for Europe (ECE UN in Geneva) all reacted by setting up working groups and programmes to examine what should be done in response to the American initiative.

Within the OECD programme, Sweden was asked to examine the subject of the human tolerance to dynamic impacts as to the state of knowledge on this topic in Europe. The answer was that very little research on the subject was going on in Europe. Most of the work at that time was being done in the United States. Bertil Aldman was then asked to take on the task of doing something about it.

Bertil Aldman was one of the few research workers in Europe who had contributed substantially to this area. Bertil was a medical doctor. But in 1962 his doctoral thesis at the Karolinska Institute was published under the title “Biodynamic Studies on Impact Protection” [4]. It is an astonishing piece of work in terms of the breadth of topics covered and the engineering detail in which each was addressed. For example, Derwyn Severy and his colleagues in the United States had conducted crash tests in which high speed cinematography was used with frame by frame analysis to derive estimates of accelerations at various points in time during the crash. Aldman’s analysis of some of their results showed that a systematic error was introduced by stretching of the high speed film and thus caution had to be exercised in the accuracy of the results. The main part of his doctoral dissertation involved seven full scale car-to-barrier crash tests in which several types of seat belt were used under various crash conditions. This involved designing and building a crash test dummy with associated instrumentation issues. The results outlined the best characteristics and geometry of the restraints tested and demonstrated the superiority of the lap and shoulder belt system compared to the other types. Bertil was particularly interested in the response of the chest to crash forces and devised an experiment in which an anaesthetised pig was placed on an oscillating table above which was an x-ray tube and below which was the film. Contrast dye was injected into the aorta. The amplitude of the movements of the thoracic organs was compared with the amplitude and frequencies of the oscillating table. This work anticipated the viscous criterion. Bertil contributed frequently to the proceedings of the Stapp conference. I met him for the first time at the 11th STAPP conference in 1967. From then on we corresponded and he was always helpful in his advice on the research which I was doing. Bertil had a strong interest in the natural world, as do I, and I remember discussing with him the possibility of producing a compendium entitled The Natural History of Road Accidents. We had both been impressed by a study published in 1960 entitled “On the Natural History of Falls in Old Age” by a surgeon who worked at the Royal Hospital in Wolverhampton, England [5].

In 1971 Bertil invited a number of people to come to a meeting to discuss the issues raised by the OECD. The official invitation came from Alain Wisner, a specialist in ergonomics based in Paris. The first meeting took place in Lyon where our hosts were ONSER (later INRETS now IFSTTAR). Eight people from six European countries were invited to a two day meeting. The outcome was to create a small, independent organisation. Its aims were as follows (I quote from the 1973 conference proceedings [6]):

- to encourage studies on the transfer and dissipation of kinetic energy inside and outside the human body
- to collect and disseminate information on the biokinetics of impact
- to serve as a reference group to other groups engaged in epidemiological studies and studies on the design of vehicles
- to engage in the training of researchers in biokinetics

So, with the official encouragement of the OECD and great help from ONSER which supported our first secretariat, the International Research Council on the Biokinetics of Impacts was formed. Members of the group would be chosen on their individual merits and could not represent nations, governments, industries or companies. We decided to have a few corresponding members from outside Europe; John Stapp and Ayub Ommaya in the United States and John Lane in Australia. Members of the group were research engineers and medical doctors including notably a specialist in rehabilitation, Professor Frederik van Faassen in Amsterdam. The Haddon matrix was part of our discussions as to where in the pre-crash, crash, post-crash sectors we should concentrate our efforts. Having a rehabilitation specialist to address the consequences of impact trauma was considered entirely appropriate. We further decided that our first task would be to organise a conference which would outline the state of knowledge on human tolerance to impact. Also to be defined were the specific areas of road trauma in Europe which differed from the United States such as smaller cars and many more pedestrian, cyclist and motorcyclist casualties. In addition we would review the available knowledge on the effectiveness of current protective devices and designs in the real world of crashes.

The first conference was held in Amsterdam in 1973. There were a mixture of invited papers and selected ones. French, German and English language texts were allowed. To round off the conference William Haddon, then at the Insurance Institute for Highway Safety, gave the closing address. Bill Haddon, like Bertil Aldman was both an engineer and a medical doctor. Haddon's address, Energy Damage and the Ten Countermeasure Strategies, was notable for references to Darwin, the Book of Job, syphilis, Hippocrates and vitamin C [7]. The structure of his ten countermeasures encompasses both good engineering principles and the recognition that car crashes are a public health problem. In all 41 papers were presented to over 150 attendees. It was a good start. The Council decided we should do it again each year.

THE FIRST DECADE 1973 TO 1982

The first 10 years of IRCOBI were a golden age for crash investigation. Once the general principles of crash protection were accepted, it became apparent that there was so much that was so wrong that could so easily be fixed. There were at least six European countries which had detailed, multidisciplinary accident investigation programmes. European governments at national and international levels were pressing for reasons to adopt or reject the FMVSS standards or develop their own national rules. The car industry was largely defensive and often obstructive. But the basic questions were always "How well does this or that standard or design work in the real world? Is it worth it? How can it be improved?"

The conference proceedings for the first decade were full of studies of pedestrian injuries and car exterior design and the limitations of various components and structures in the car interior. The effectiveness of various FMVSS requirements in the context of European car design was evaluated; windscreens, door latches, steering wheels and columns, seat belt retractors, seats and child restraints were all candidates for regulations. At the same time there were many hospital-based studies of patterns of injury and the mechanisms of specific injuries. What was gratifying was to see how doctors and engineers worked on projects together to form the medical-engineering links which the study of the biokinetics of impact injury requires. In many instances that involved breaking down the traditional bureaucratic boundaries between the disciplines and in universities, in particular, challenging the rigid separation of medical and engineering faculties.

The whole notion of crash protection and biomechanical research in the late 1970s and early 1980s was new to the general public and the conferences generated much interest by the press. There were the obvious controversies over animal and cadaver testing but also the whole idea of making cars safer was open to debate. Risk compensation arguments were paraded by some observers; "If you make cars safer people will drive more dangerously. It's the nut behind the wheel you should be working on." Politically, compulsory seat belt use laws were under discussion in much of Europe. Because of these and other issues there was considerable public interest in the conferences. At several meetings we had to organise a press room with additional telephones and facilities to interview speakers as one measure of the public interest in this new subject.

Mathematical modelling of crash circumstances began in the 1970s and in 1980 MADYMO appeared in the IRCOBI proceedings [8]. In subsequent decades with the growth of computing power modelling was to become a major activity reflected in all the conference proceedings.

The Board of the day was keen to involve the other transport modes and other situations where blunt trauma occurs. In this decade we had the first paper from the military side with a study of thoracic response to baton rounds (rubber bullets) using a high speed x-ray technique [9]. In 1979 we had the first paper on the characteristics of fatal aircraft accidents by a pathologist from the Royal Air Force [10]. In 1982 there was an interesting paper of skull fractures of the temporal bone to skiers in Switzerland [11].

THE SECOND DECADE 1983 TO 1992

The problems which were described in field accident and hospital-based research illustrated the need for more experimental work to find out what really happens in a crash. PMHS studies were reported in the first decade but they increased greatly in the 1980s. Together with the development of the Hybrid III, sled testing, and examination and validation of proposed injury criteria for each body region occupied the majority of the work presented at IRCOBI in that decade. Head injury criteria in particular were a major area of research with increasing awareness of the limited value of the Head Injury Criterion. The biomechanics of impacts became much more technical and institutionalised and became an accepted part of the engineering scene.

Field accident studies continued at the national level in several countries but it is to the shame of Europe that all attempts to establish an agreed structure for a Europe wide data base, equivalent to the FARS and NASS/GES programmes in the United States, failed. NASS and FARS, by generously allowing open and free access to information on the characteristics of crashes in a structured sample in the United States, has resulted in hundreds of useful research papers and provided a longitudinal timeline spanning almost four decades. Despite grandiose statements from the European Commission and others, the enormous gap between aspiration and funding, as well as issues of confidentiality, and national disagreements on how to classify injuries, meant that all attempts so far have been a failure.

In the 1980s there was a real transformation within the car industry. Some manufacturers had always had a positive view of safe design but in the 1980s there was a more general realisation that making safer cars actually helped sales. Safety moved from being the reluctant acceptance of the regulations, where the aim was how to produce the most economical design which would just pass the rules, to a positive view of how could better crash protection be provided. The introduction of the New Car Assessment Programme in the United States in 1978 began the process of a star rating system to inform buyers about the safety of the cars that they might buy. In the 1980s various national consumer associations in Europe began programmes for assessing cars from a crashworthy point of view and informing the public of the results. IRCOBI papers at that time were often about defining which were the most representative crash tests to use and what should be the appropriate injury criteria. Those consumer organisations later came together to form, with others, the EuroNCAP star rating system in 1997.

EuroNCAP has now become so powerful that achieving five stars dominates car design decisions. That process means that cars often exceed substantially the requirements of the regulations. In Brussels, in particular, the byzantine process of developing or modifying an EU Directive, originally conceived under the principle of the removal of technical barriers to trade rather than a safety regulation, ensures that what is finally agreed is often based on the state of knowledge of 10 years ago. There are now many national and regional NCAPs together with a global NCAP which aims to harmonise the process at least in countries which do not have their own national systems [12].

THE THIRD DECADE 1993 TO 2002

The 1990s saw a big increase in modelling studies as well as a proliferation of the dummies, with dummies specific to front, side and rear impacts, representative of various sections of the population and for certification or research purposes. There was greater recognition that a single crash test for each category of impact, frontal, lateral and rear, plus a static roof strength requirement for rollover protection, could not adequately reflect the range of crash types and severities in the real world. How to optimise design across the population of people and the population of crashes became a popular area of research. That has led to much research and development of adaptive systems.

With the amazing increase in computing power, simulations of enormous complexity were done but establishing the geometrical and engineering properties of the tissues in the human frame still remains a formidable challenge. Validating models against physical tests became a common issue and remains one today.

EuroNCAP, when it first started, included pedestrian testing but that did not initially stimulate much obvious change in vehicle exterior design. With the rise in vehicle ownership in low and middle income countries, however, there became a greater recognition that, on a global basis, the exterior of the car injures more people than the interior.

The 2001 conference was due to start on October 10th in the Isle of Man. September 11th 2001 is a day we all remember. As the skies closed over the United States, some people were suggesting that the conference should be cancelled. However, the Board of IRCOBI decided that the conference should go forward and in the event almost everyone who had registered turned up and we had only a few US government employees who were compulsorily grounded. The dedication of the delegates was impressive. We even managed to redirect one delegate who was heading for the Isle of Wight.

THE FOURTH DECADE 2003 TO 2013

This last decade has seen the greatest changes in impact biomechanical research since IRCOBI began. The power of computational modelling has come to dominate how vehicle safety systems are optimised across the range of crash situations and the variety of human response which they trigger.

In addition, the traditional view of mechanical failure is now shown to be an inadequate approach, particularly for neurological trauma. As Barclay Morrison has put it: “A fundamental difference between inert engineering materials and biological tissue is that the latter is alive and performs some active function…Cell death and changes in electrophysiological function are more meaningful than mechanical failure criteria” [13]. Those sentences, coupled with the wizardry of optical coherence tomography and the atomic force microscope have opened up a new world of biomechanics.

These changes have meant that new disciplines such as cell biology, computational modelling, mechatronics and applied psychology, have been introduced alongside the traditional ones of engineering and medicine.

On quite another dimension, somewhat belatedly, IRCOBI has instituted one of the original aims of the organisation which was to train researchers in the biomechanics of injury. AAAM started such courses in 1983 in the United States. They were very successful and it became obvious that similar courses were needed around the world. A number of such courses have either been added on to the annual IRCOBI conference or in several instances have been conducted by IRCOBI in countries where there is little activity in the subject, but where recognition that the growth in motorisation in the developing world requires more biomechanical knowledge to tackle the increasing levels of trauma. Hence so far we have done such courses in Poland, India and Malaysia.

With globalisation, this is an area in which I believe IRCOBI could make a real difference. Wearing another hat, over the last 30 years I have worked sporadically with the World Health Organisation which aims to develop a better response to the increasing amount of road trauma generated in low and middle income countries with the rapid growth of vehicle ownership. Those efforts from many people culminated in the World Report on Road Traffic Injury Prevention [14]. However, it is the nature of United Nations agencies to operate within the public sector at the national level and that makes it difficult to develop enthusiasm and knowledge transfer in specialised areas like biomechanical research which should lead to good engineering practice. Furthermore, being a health organisation WHO lacks the engineering skills and contacts which are necessary to build on the medical-engineering links which are necessary for the formation of effective local projects. IRCOBI is in the process of developing IRCOBI ASIA in part to encourage these activities in low and middle income countries. Perhaps IRCOBI could develop links with the WHO to promote a more integrated and scientific approach to road trauma in countries on the growth curve.

THE FUTURE

What has changed so obviously in the last few years is the range of subjects in which research is presented at the annual conference. There are dangers in this in that no-one can be totally current in crash injury epidemiology, cellular biomechanics, blast injury mechanisms, computational modelling, dummy development and validation, the man machine interface and physiological responses when driving in field operational tests. This leads to the danger that the annual conference can become more fragmented and an increasing number of attendees are only really interested in a minority of the papers presented. What should be done? Should we structure more parallel sessions in specialised topics or even select certain topics for each annual conference?

Historically IRCOBI has focused on injury biomechanics, almost exclusively in the road vehicle context. The application of electronics to the car and the road environment and their integration has the capacity to radically change injury risk on the road. Car to car communications, car to traffic management interaction, emergency response, autonomous braking, etc. lead eventually to the self-driving car which never crashes. What then for vehicle related impact biomechanics?

Fundamental to what we do is based on what happens to real people in real crashes. In this area, especially in Europe, there is not enough in-depth crash investigation. The CIREN programme in the United States is a good example of what can be learnt about the details of specific mechanisms of injury and how successful preventive design is in the real world.

IRCOBI has also ventured outside vehicle collisions into sports biomechanics and blast situations. With the development of sensing technologies, we have also ventured into the near collision period, say 2 seconds before impact, and all the things which might be changed before the crash starts. Beyond that there is also currently much interest in field operational testing and naturalistic data as a means of understanding underlying factors which may lead to high risk situations and crashes. The storage of large quantities of data on speed, braking, steering, gear changing, eye movements, physiological responses, all this can be coupled with video recording of traffic conditions. Analysis of such data will undoubtedly lead to a greater understanding of the factors which increase risks which will lead to better designs of the road system and the vehicle. Those areas are well away from impact biomechanics.

One particular aspect of the post-crash scene is the physical, social and economic consequences of traffic injury. We have the AIS but the assessment of impairment and disabilities is not yet described adequately in a systematic and objective manner. One of the original members of the IRCOBI Council was a specialist in rehabilitation but that aspect of trauma did not develop as we had hoped.

As an academic I follow the changes which globalisation brings with great interest. The more enterprising universities have developed campuses or specific departmental links all around the world. More recently distance learning is changing the nature of a university itself. Witness, for example, M.I.T. and Stanford University where many courses are now freely available on-line. A university lecture is becoming a thing of the past. Instead, careful production of a series of lectures with all the graphics and video done to a professional level make the chalk and blackboard obsolete. Such an approach by IRCOBI on impact biomechanics would help to increase the number of people who need to know more about the subject.

It seems to me that we should embrace globalisation because the great majority of the world is just coming to the car as a first generation event. What is technically possible in the rich, developed world will not be available globally for a generation or two. Thus special vehicles appropriate for low and middle income countries, especially in the megacities which are now being created, offer a challenge of developing good crashworthiness for very inexpensive designs. The introduction of the Bajaj quadricycle with a speed limit of 70 km/hr is an example of a design which is likely to be substantially safer than the current three-wheeled taxis of Asian cities [15].

Figure 1 is a projection of the changes in road fatalities from 2008 to 2030 for the regions of the world as defined by the WHO. Europe will have fewer deaths, the Americas about a quarter higher but much greater changes in South East Asia, the Eastern Mediterranean region and Africa especially with a 127% increase projected [16].

	WORLD	AFRICA	THE AMERICAS	EASTERN MEDITER-RANEAN	EUROPE	SOUTH EAST ASIA	WESTERN PACIFIC
2008	1,438,047	246,931	157,702	167,571	121,870	368,818	375,156
2015	1,676,000	325,000	169,000	202,000	109,000	459,000	412,000
2030	2,191,000	562,000	194,000	282,000	87,000	620,000	446,000
% Change 2008-2030	52%	127%	23%	68%	-36%	68%	18%

Fig. 1. Projections of traffic deaths by WHO regions to the year 2030 [16].

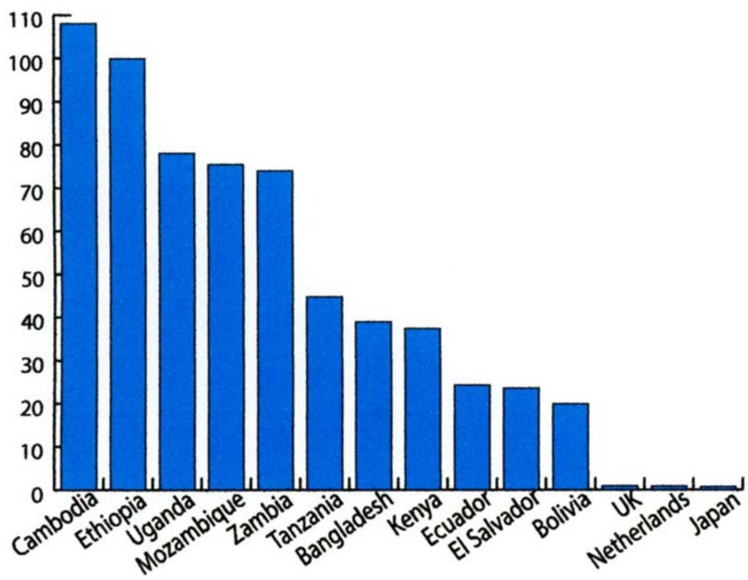

Fig. 2. Annual traffic deaths per 10,000 motorised vehicles in a selection of countries [17].

From figure 2, assuming an annual death rate of 50 per 10,000 vehicles and the life of a car at 10 years, then one car in 20 will be involved in a fatality. Assuming further that for every fatality there are 10 casualties with serious injuries, every other car on the roads in sub-Sahara Africa will injury someone seriously over its working life. This is one way of showing that the application of classical crashworthiness principles to the vehicles in the developing world is going to continue for the next two decades. There is still much for IRCOBI to do.

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