TOOTH DEVELOPMENT IN CATTLE
UNIVERSITY OF ILLINOIS (1957–1959)

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Introduction

In 1956 I worked as a clinical registrar in orthodontics at the London Hospital. One afternoon the dean, Maxwell Horsnell, said: “There’s a research fellowship in paedodontics [earlier term for paediatric dentistry] available at the University of Illinois in Chicago for a year. If you'd like to go, I'll sponsor you." I asked a few questions, being particularly concerned I would have to work as a children's dentist rather than an orthodontist. I had found clinical dentistry limiting but was intrigued by orthodontics, which was dependent on an understanding of the complex inter-relationships between growing jaws and the development and eruption of the teeth. Besides, there were numerous theories and approaches to treatment and many debates. I viewed dentistry as a means of making a living and very much a nine to five job. I had never considered being a full-time research worker realizing, if I became one, I would have to totally commit myself and be prepared to sacrifice my other interests. "Well if you are interested, let me know tomorrow," the dean said, waking me from my reverie.

It was an opportunity of a lifetime so I agreed. Horsnell had all the necessary documents for me to complete, for registration with the University of Illinois and for a temporary visa to allow me to become a student in the USA. One section had to be completed by Guy’s Hospital where I had trained as a student in 1944-50. They listed my grades and gave an estimation of my academic suitability, stating Mr Brown had done nothing whilst a student at Guy’s to draw attention to himself confirming my view that it was because there weren’t enough other applicants when I qualified in 1950 that I was appointed to a coveted Guy’s house post.

The University of Illinois

I arrived in Chicago in February 1957. The paedodontic [called pedodontic in America] research director, Prof Maury Massler, a charismatic man, quickly earned my respect. I have been forever grateful for his helping me to recognize that I would find a satisfying career in dental research. Nobody in dentistry, until I met Massler, ever suggested I had the requirements for an academic career. I had always been in awe of the academic world. He was a friendly person.

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Although never wasting time on idle talk Massler made himself readily accessible to his research students. As soon as I arrived he asked me to look at the data derived from an investigation carried out by a general practitioner on the effectiveness of the oral screen as an orthodontic appliance for correcting protruding teeth. This modest project introduced me to searching the literature for appropriate references and entitled me to become a collaborative author for the subsequent paper.[1]

Before I had completed that work Massler switched me to join Dr Henry Rosenberg looking at the stipple patterns of human attached gingivae. Hundreds of colour photographs were taken and I analysed the distribution and patterns of the stipples without coming to any convincing conclusions. Then Massler got me thinking about the difference between alveolar bone and basal bone, which in the mandible forms the main structure of the jaw, giving attachment to the muscles. It was my first experience of finding that the perceived view of the differences as understood by orthodontists did not tie up with the known and readily ascertainable facts. My curiosity was aroused. By considering the embryology, growth, histology, anatomy and pathology of the mandible and maxilla, I arrived at a better perception of the differences between the alveolar processes and the basal bone. Massler suggested the differences were most likely to be attributed to the characteristics and properties of the overlying attached gingiva and the alveolar mucosa. He posed the question: why was the bone under the attached gingiva more labile than the bone under the oral mucosa? The next stage would have been to devise experiments, but before I got to plan any, Massler put me on to a cattle project.

This was an unexpected assignment for a dental school and the last animal that I had imagined I would be working on, as the school's experimental animals were the diminutive mouse and the golden hamster.

Fluorosis in cattle

Massler's involvement with cattle came about because the farmers in Utah were suing the United Steel Corporation for damages. They claimed excess fluoride had been deposited on their pastures and poisoned their cattle.

The Columbia-Geneva Division of the U S Steel Corporation took over from the American government the steel plant it had built during World War II near Provo in Utah. The Corporation added new processes including a steel rolling mill. The iron ore for this plant came from Iron Mountain located 260 miles south of Provo. At the time it was not known that this particular ore was high in fluoride salts. In 1951 Kennecott Copper Corp., located in the Salt Lake valley the next valley north of Utah Valley (Geneva), was monitoring vegetation in both valleys. It discovered the vegetation round the steel plant was heavily

[1] A K Toepfer, M Massler and W A B Brown, Effectiveness of the oral screen in the treatment of upper incisor protrusion, *Am J Orthodontics* 1959; 45: 759-767.

contaminated with fluorides so privately advised the Steel Corporation of the situation.

The alfalfa plant, almost ubiquitous in the area, was used to make hay for livestock. Because it grew "everywhere", alfalfa was used as an indicator plant in determining areas of fluoride concentration.

The U S Steel Company enquired from the Aluminum Company of America, which had extensive experience with fluoride emissions what the consequence might be. U S Steel learned there could be damaging effects on livestock and serious problems with the farming community, so sought assistance.

Advice was sought from, among others, Utah State University, especially Dr D A Greenwood, head of the Department of Biochemistry. Greenwood held a BS degree in animal nutrition from Iowa State University and a PhD in pharmacology from the University of Chicago. For his Chicago thesis he reviewed fluoride toxicosis and was considered one of the experts in the field.

In 1949 Paul Christofferson, a veterinarian, took over the diagnostic laboratory of Utah State University in Provo. He had qualified during the war and served in army veterinary hospitals in Burma and China, looking after horses and mules. Over 15,000 of these animals were used as pack animals because there were few roads.

Christofferson remembers[2] one of his first involvements with the fluoride problem was when a Mr Bunker, a dairy farmer close to the Provo works noticed his cattle, which usually fattened for market in two years, took four years to gain the same body weights. Christofferson visited Bunker's farm with Greenwood. He lassoed a steer, held it against the corral fence, grasped its nostrils and examined the animal's teeth. He saw the telltale fluoride hypoplasia stained lines on the incisor teeth and the characteristic wear patterns of fluoride enamel and dentine damage. Bunker's alfalfa had a heavy contamination of fluoride, yielding high levels of fluoride in the teeth and bones. The fluoride levels of the bones compared with 3.2% in raw rock phosphate. Bunker was an obliging farmer who gave Christofferson round the clock access to his animals. The first behavioural abnormality Christofferson noticed was that at first the animals drank normally from a cold spring stream running through the farm; then they suddenly lifted their mouths out of the water and licked their teeth. He also noted other cows spat cud out of their mouths for no apparent reason and he saw dotted round the pasture numerous small partially chewed cuds. Subsequently he read in the literature that cattle near Fort William in the British Isles had similar behaviour patterns. The researchers attributed these patterns to tooth pain in the incisors when the animals drank water and in the premolars and molars when the animals chewed on a sensitive tooth from exposed dentine after enamel had failed to form and cover the nerve rich tissue completely. Christofferson remembers the publication reported that cattle of Fort William chewed the cud 72 times before swallowing. He found the normal cattle of Provo also chewed the cud about 72 times. Cattle with severely affected

[2] Paul Christofferson, Personal communication, 1995.

teeth chewed their cud from 10 to 36 times before they spat it out. The connection between excess fluoride and damage to bones and teeth has been known for many centuries.

U S Steel decided to address the problems associated with excess fluoride and met with representatives of Reynolds Metal as well as ALCOA who were in the aluminum business. They had bad experience with the farmers who distrusted the industry. U S Steel engaged Dr Mortenson (a PhD in animal physiology) who, with the help of Greenwood and Christofferson, filmed the fluorosis problem around the steel plant: how it occurred and contaminated the pastures and affected the teeth and bones of the cattle who ingested it. This film was shown to the Board of Directors of U S Steel in 1952.

The Company took the unprecedented step of admitting their industrial activities had contaminated the pastures and that they would compensate the farmers for their losses. The Company put together a claims form which the farmers completed and submitted. Meanwhile U S Steel would do everything technically possible to reduce the emissions from their plant.

Fluoride was being given off mainly in the sintering plant where the crushed ore was heated to form small rocks of mixed ore and waste in preparation for smelting. Limestone was added to the crushed ore. It combined with the fluoride as it was heated in the sintering plant, reducing the fluoride emissions.

U S Steel hired Paul Christofferson in 1952 as a veterinarian to evaluate damage to livestock and to represent the Company in its negotiations with the farmers for compensation. The Farm Bureau (equivalent to the National Farmers Union in England) sponsored local farmers who formed the Farmers Fluorine Adjustment Committee. A group from U S Steel under Christofferson's direction would examine the teeth of cattle on all affected farms. They made their assessment of the damage according to a dental fluoride severity classification, worked out originally for humans by Trendley Dean[3] and modified by Greenwood. The farmers accepted the classification because they were told the Utah State University had carried it out.

In the beginning the Adjustment Committee employed their own veterinarian, but sacked him after the cattle on three or four farms had been assessed. They trusted Christofferson's assessment so all but a small group of farmers, whose farms were between fifteen and thirty miles form Provo, settled out of court. The others lost their case some years later because they insisted that once the animals had been in a fluoride zone, they were damaged by the intake of fluoride, no matter what the amount. There was no chance they could win on such an assertion as it was well established that the teeth could only be damaged by fluorides in the course of their development. Their claim was also rejected on the grounds of the distance of their animals from the emitting

[3] H Trendley Dean, 'The investigation of physiological effects by the epidemiological method', in F R Moulton (ed) *Fluorine and Dental Health*, Washington, DC: American Association for the Advancement of Science, 1942.

chimneys. It had been calculated that the highest concentrations of fluoride would be at a distance of ten times the height of the chimneystack. The animals at fifteen miles distance from Provo were well outside the range of possible vegetation contamination.

After all the claims had been settled in 1955 Christofferson negotiated with the farmers that any further claims would be for animals born on the farms and would be based on tooth damage from a classification specifically worked out for cattle. The first step in making this classification was to determine the chronology of tooth development. Christofferson approached Greenwood who advised him to contact Dr Isaac Schour, dean of the Dental School at the University of Illinois, who put him in contact with his colleague, Professor Maury Massler. Schour and Massler had established the chronology of tooth development for humans.[4] They agreed to carry out the investigation with Christofferson's help as long as there would be no legal involvement. Eventually Massler proposed a budget of $40,000 to which the U S Steel Company agreed.

Chronology of tooth development

By the time I arrived in Chicago the technique for obtaining radiographs of cow's teeth had been established by Christofferson. The first films had been examined by Milan Schijatschky, a graduate from Switzerland. He plotted the different stages of development for each incisor teeth on large-scale drawings.

It was known that even slightly raised levels of fluoride led to distinct lines or bands on the teeth which were associated with a disturbance of enamel and dentine formation. The lines and bands could be identified with the precise time the tooth was forming and occurred as the ameloblasts forming enamel and the odontoblasts forming dentine did so in a strictly sequential pattern. Any excess fluoride poisoned cells impairing, to different degrees, their ability to form normal mineralised enamel or dentine.

Christofferson was amused by Schijatschky and remembers him helping to take the radiographs and politely asking the cows to open their mouths while he put the X-ray films in their mouths, as if they were sitting comfortably in a dental chair (Fig 1). At the same time colour transparencies were obtained of the incisors (Fig 2).

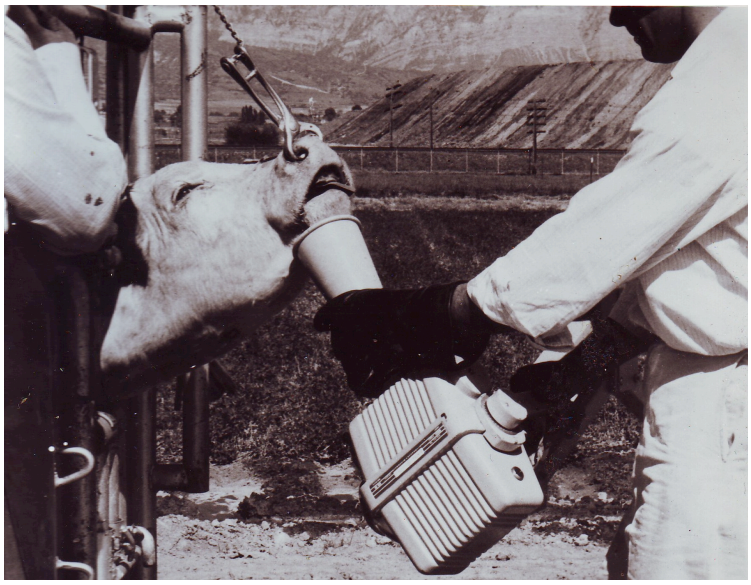
Schijatschky had to return to Switzerland and I took over the project from him. He was a very competent worker and I am sure if he had stayed on, he would have accomplished all that I did and more, and in his own particular style. I was very fortunate Massler entrusted the project to me. I now realize that, during my first weeks in Chicago, he was testing my competence.

While I acquainted myself with the radiographs that Schijatschky had examined (Fig 3) and made sure I understood how he derived his results from

[4] I Schour and M Massler, Studies in tooth development: the growth pattern of human teeth, *J Am Dental A* 1940, 27: 1178-1193.

the original pilot study, steps were taken to locate pedigree herds in Illinois whose owners would agree to their animals being x-rayed. The important point was that pedigree animals would have guaranteed correctly recorded dates of birth. Massler and Christofferson found three managers prepared to collaborate. Walter Davies had Aberdeen Angus cattle at Model Farm in Mundelein, Brad Scott was responsible for White Faced Hereford cattle at Northern Pump Farm in McHenry and the manager of Curtiss Candy Artificial Breeding Services in Cary had dairy and beef bulls. We radiographed the Brown Swiss dairy herd of the College of Agriculture of the University of Illinois in Urbana. Christofferson also arranged to radiograph over 300 registered Holstein dairy cattle in Utah.

Figure 1 Radiographing teeth of cattle. The animal was restrained by a stanchion and the head was immobilised with a nose-lead. The x-ray film was contained in a packet and secured by an elastic band behind the incisors



I was responsible for making first enquiries about suitable radiograph equipment. I knew nothing about the virtues of different machines. After I identified several machines Marvin Weiss took over and contracted with a firm to hire a portable unit. Weiss was a part time restorative dentistry clinical teacher and was very helpful on many occasions. He was a close friend of Massler from their student days.

I went with Christofferson to visit Brad Scott at Northern Pump Farm to determine under what conditions we would be radiographing the animals. Scott, a big man with a Stetson hat, drove his large estate car as if it were an unbroken horse trying to unseat him. He travelled at speed down narrow lanes, ignoring cross roads as if he was the only rider out on the prairie. All the time, even while driving at speed, he continually called up his cattle men on the car phone ordering them to move the yearlings here or the two-year olds there. It was very impressive. Scott was big man with a restless energy. In between he told us of the move of the herd by train from Texas. The Hereford pedigree herd was a sideline of the owner's main operation of manufacturing pumps.

When we were radiographing these Hereford cattle Christofferson noticed some animals had evidence of excess fluoride intake. It turned out that part of

the farm nutritional strategy was to feed a supplement containing raw rock phosphate which had been imported from the island of Nauru in the Pacific Ocean which turned out to have a 3.5% fluoride component. Usually rock salt for cattle would have been purified and the fluoride salt extracted. I imagine Scott switched to a new brand. In retrospect it never occurred to me at the time that this fluoride contaminated feed might have affected tooth development and eruption rates.

Figure 2 Anterior view of the teeth

Collecting the data

Taking the radiographs and the photographs was a combined operation with Christofferson, Earl Allred, Weiss and myself. The farm workers guided the animals into the animal crush. Once the animal's body was restrained, Allred and Christofferson positioned its head and secured the x-ray film in its mouth. Massler aligned the radiographic machine along the correct axis at an 18-inch target distance. I pushed the timer button of the radiograph machine for two fifths of a second exposure at 60 kv and recorded the animal's number. The whole procedure was effortlessly done. Christofferson always said it was largely due to Allred's exceptional empathy with animals. It helped too, that we all got on very well together.

The Aberdeen Angus herd at Mundelein was near enough to Chicago to make it a day trip. I met Massler at first light at the end of the bus line at Oak Wood. The morning was freezing cold and I was inadequately dressed. I had arrived half an hour before I was due to be picked up and thinking I wouldn't survive in the cold, went to a nearby apartment block and waited inside the foyer. It was better out of the wind, but even there I felt the freezing cold was getting at me. I was concerned that Massler might arrive and miss me at the bus stop, as I ran to and fro between the foyer and the bus stop. Happily he arrived before I had to seek more drastic assistance. I was no longer convinced that dying of cold was an easy way to go. It seemed to me there were some very unpleasant hours before you died. It was a sobering lesson.

After we had taken the radiographs at Northern Pump Farm, we left the x-ray machine on a Friday evening at the Mundelein farm for an early start. When we arrived on Monday, a large Cadillac was drawn up in the yard and a big guy wearing a broad rimmed, mob style hat, was sitting at the wheel. He turned out to be the owner of the Aberdeen Angus herd. He came to check out the

arrangements his manager had made with us. Christofferson told him we were from the University of Illinois. It seemed to satisfy the boss who immediately drove off. Christofferson joked that the boss looked as if he could have belonged to the mob. The manager confirmed had once been a close associate of Al Capone, the famous mobster. He now owned half of the Schlitz beer distribution network in the Chicago area and, said the manager, he didn't buy that operation in the normal course of business!

Figure 3 Above, occlusal; below, lateral view to show first incisor forming at a right angle to its final alignment in the mouth

While we were radiographing the animals Christofferson learned from the manager that the previous year they had bought a very expensive pedigree bull from Aberdeen in Scotland, but the animal had died. When I analysed the Mundelein cattle radiographs I found that, according to my chronology tables, one bull was a year older than the year stated on his pedigree record. The manager had also told Christofferson they had bought an Aberdeen bull in a local (US) sale. He concluded from my findings that the Mundelein farm owner might have transferred the deceased expensive bull's pedigree credentials on to the locally purchased animal.

Radiographing the bulls at the Curtiss Candy Artificial Breeding Services farm was a memorable experience. The various breeds of bulls were kept under a variety of conditions. Some were in fields with special exits large enough for a man to squeeze through but too small for an infuriated bull to follow. I was told beef bulls were comparatively docile, but dairy bulls, especially the Channel Islands breeds, were treacherous and ferocious. The bulls on this farm were remarkably handsome creatures and among the largest I had ever seen.

The animals were so large and physically strong they were secured in a huge heavy timber crush (an ordinary metal crush would have been demolished). Their keepers who held on to lines secured in the animal’s nose ring led the bulls to the crush. One vast bull had eight men to restrain him and yet he still managed with one enormous swing of his head to have all the men

sprawling on the floor. We all responded to the special circumstances and Allred exercising his mesmeric charms calmed the turbulent animals. We witnessed a brilliant display of animal power, slyly curtailed by human ingenuity.

Obtaining the radiographs of these highly prized animals was a marvellous demonstration of collaboration with the farm managers. It was very impressive to see how they and their workers did all they could to help us to achieve our goal. At the time I had no understanding of the trouble and expense to which we put the farmers.

Analysing the radiographs

Only when I began to analyse the radiographs did my contribution to the project really begin. The incisor region of 869 living animals had been radiographed, giving 6952 teeth to examine. Each tooth had to be identified at one of six locations on the chronology ladder, making a total of 41,712 possible observations. When I first saw Milan looking at the radiographs, before I had any idea that he was looking at developing cattle's' teeth, I thought he was studying human toes. I started at the bottom of the learning curve. I used a x5 magnifying glass. I found it was easy to identify a tooth as soon as it began to form, even before mineralisation, because of the space that was made for it in the bone, a space that enlarged as the tooth grew and the bone was resorbed away by osteoclasts. Early mineralisation of a developing crown was readily recognized. After a little experience I could readily identify several stages from the completion of the crown to the formation of the root. The greatest care had to be taken when tooth development was at an interim stage. Then it was important to examine the radiograph in complete darkness. With time I realised there were other related details that could be distinguished. The resorption patterns of the deciduous teeth were distinctive and were all additional events I could describe.

The stage of eruption, especially when the tooth was about to emerge into the mouth had to be assessed using the photographs taken at the time the radiographs were obtained.

I thought of a very simple device to test out the sequential nature of tooth development and eruption. I drew for each animal a two-dimensional outline of the crowns and roots of the four incisor teeth on a 5 ins x 8 ins card. Then, for each animal, reading off the stage of development of each tooth from the radiographs, I coloured in red on the cards the stage reached. I arranged the cards in strict age sequence and then holding the cards tightly together, flicked through them in the same way that one could look at animated cards of a Charlie Chaplin sequence. It demonstrated very clearly all I wanted to show, but alas, there was no way such a procedure could be published.

Background reading

As the days passed I realized, while working on the material, how little I knew about tooth development and the formation of enamel, dentine and cementum or even the periodontal ligament and the supporting bone. Learning about these complex and sequential processes, because I needed to understand exactly what it was I was looking at in the radiographs, was completely different from having to know about them simply to answer an examination question. Schour and Massler[5] had published their studies in tooth development and I absorbed the information quickly. Needless to say it was not until the advent of the Transmision and Scanning electron microscopy in the 'sixties and its use in research into tooth development that the process become properly understood.

Even before this project I had some understanding of farm animals. I had always been interested in anything to do with the countryside and in the war years 1939-45 had a variety of summer holiday jobs on farms. I was full of impressions disguised as information. I soon realised that I would have to know about the different breeds of cattle and their distinguishing characters. I was only vaguely aware that animals had been selectively bred to produce beef or milk. I knew nothing about calves' gestation time and that it was the same as the nine months of human gestation.

Christofferson gave me a crash course in all the most important aspects of animal husbandry and with accompanied visits to agriculture departments in Urbana and by reading the current textbooks, I learned fast.

The exhibit

After I had established the main landmarks in the development and eruption of the incisors and the incisoform canine it was suggested an exhibit should be prepared for the 1958 annual Veterinarian Conference in Philadelphia. My job was to rough out some ideas for presentation and choose the radiographs on which the staff of the Illustrations Studios would draw up some tentative ideas for a design. Hooker Goodwin, the professor of the department, was an artist in his own right and a bit of a *bon viveur* (he introduced me to drinking Martinis in the middle of the afternoon). An anglophile he could not have been more supportive, taking a personal interest in all stages of the preparation. His department designed and constructed the exhibit. Ramona Morgan did the artistic work and sophisticated pipe smoking craftsman, Emil Hospodar, an Assistant Professor of Medical and Dental Illustrations, expertly constructed and assembled the separate components.

I was always aware of deadlines and wondered sometimes how the work could possibly be completed in time, but the secretary of the department, Janice Lindeman was very helpful and all difficulties were overcome. The final exhibit consisted three panels: the central one exhibited photographically enlarged illuminated radiographs of nine key stages with tracings to show the important

[5] Ibid.

features; a side panel showed the technique; and a second side panel graphically summarised the results. I learned much from my participation in the exhibit, especially from the artists who stressed the importance of simplicity, clarity and of allowing the illustrations to speak for themselves so you only needed a few words of explanation for the viewer to be able to understand.

I often wondered about the total cost of the exhibit, but during my time on the project money never appeared to be a problem. The exhibit was eventually given to the agricultural department of the University of Illinois in Urbana.

Trips and visits

Once I had the radiographic data analysed and Massler thought I had the chronology story at my fingertips, he sent me off on short lecture tours to different universities. He was keen for me to take on board the idea that the incremental formation of enamel and dentine followed the pattern of "tree ring" formation. It was true for enamel and cementum, which were added in increments to the external surface of the crown; but not exactly so for dentine as the first layers form on the inside of the future crown and are added incrementally within the root, thus leading to a narrowing of the pulp diameter until it may be totally filled with layers of dentine.

I visited two or three departments in a week staying in centrally located hotels, often traveling by plane. It was very much a whistle stop tour, with no time to visit the sights of any of the places I visited. I remember one identical snowy white congress-style building after another.

I had a week's visit to Provo, Utah, to see where the offending United Steel Company's steel works was located. I flew there with Noel Martin, a visiting professor from Sydney. We both made presentations to the United Steel representatives. These were my first experiences of lecturing and I have no memory of how effective I was. Christofferson looked after everything. He was marvellous as the companionable expert. He was a committed Mormon and abstained from alcohol and strong drinks like tea and coffee (the Mormons were years ahead in recognising that coffee was bad for you), but he never imposed his beliefs on his companions. Whenever I was in his company, there was always the possibility of mixing work with some form of relaxation. In Utah he took us up narrow roads to a ski resort and I recaptured for a moment the feeling of being back in Europe, an illusion that was quickly dispelled when an attractive young blond student waitress gave me a wine glass full to the brim of Crème de Menthe as my after dinner liquor. I drank it and have never been able to drink the sickly sweet green fluid again.

However serious the Mormon religion it never dampened Martin's sense of humour. One day one of the Mormon Elders who worked in the same department as he did had picked up a farm record book from a farmer. On one page someone had written:

The bee is such a busy soul,
he has no time for birth control,

and that is why in times like these,
there are so many sons of bees.

In Provo I examined numerous mandibles and maxillae of cattle that had been partially dissected. Though it was wintertime I sat outside at a table in the bright sunshine. Because of the dryness of the air I did not feel the cold. The more I worked with the cattle project, the more I realised how much research Christofferson had done. He was the go-between for U S Steel and the several universities carrying out research with its money.

Whenever Christofferson was in Chicago I gave him a progress report. After we had exchanged ideas we would go for a meal in some agreeable restaurant down town Chicago. On one occasion we went to see *My Fair Lady.*

Chicago stockyards were famous, especially from Upton Sinclair's exposé of the Chicago meatpacking industry in his book *The Jungle* (1906). I went along with Paul to visit the abattoir and was horrified to see the way the animals were killed. They were tightly confined in a metal lined pen and the slaughterers stepped over the struggling animals to stun them with their swinging sledgehammers. The dead animals were hooked onto overhead gantries and the butchers set about disembowelling them. I watched as they sawed the carcasses into cuts and joints and a multiplicity of other bits and pieces for offal, with hoofs and horns used for glue and other unknown uses, The heads were cut off and went on their separate route to have their tongues removed. What happened to the teeth I have no idea, unless they were ground down with the bones into bone meal fertiliser. It seemed that nothing was wasted. Veterinarians were on hand to make sure none of the animals were diseased. It seemed to me to be a boring and tedious job for a professional and I wondered how long they stuck it.

Attached to the stockyard was a steak restaurant where even the smallest steak served would have satisfied the hunger of four people with my kind of appetite.

Other projects

A veterinarian student became interested in one aspect of the cattle project and one of Massler's MSc students, Ricky Pineiro, studied the gingival tissues. I confess I did not take particular interest in their projects and was aware that I was being quite territorial as far as giving them access to material that I had personally acquired and prepared. We worked in a very competitve environment. I thought I knew how to deal with the problem, but in retrospect I feel a bit guilty. As I write I remember Maury Massler spoke some guiding words to me.

Master of Science

During my first year at Illinois it had never occurred to me that I should spend a second year in America to do a Master's Degree, though that was what most of the post-graduate students were intent on doing. I was very naïve. I

was happily immersed in the projects I was given to do and I enjoyed the seminars, the arguments and disputes. I was totally engaged and even had time to go to evening classes on philosophy, reading Plato's *Republic* and many other of his writings. Aristotle was more difficult. I also read Bernal Díaz's *The Conquest of New Spain* and many other books. Chicago was a marvellous city of opportunities. There was time to visit the Indiana sand dunes at the weekends where friends had summer cottages. It was there I met a doctor who, when I was wondering about the wisdom of staying on for another year, asked me if I was enjoying what I was doing. When I answered enthusiastically how much I was, he simply asked: “What's the problem then?" I should add he was Jewish whose family had been in Germany during the war: he knew all about making the most of life.

Once I made up my mind to take an MSc course I had to decide on a project. I imagined that my early work on the differences between the basal bone and alveolar process bone would be a challenging project, more so than the chronology of tooth development in cattle. I had found the cattle project very interesting and enjoyable but did not believe, with my limited experience, there was enough material to present as a thesis. Happily Massler persuaded me there was and so I registered it as my chosen project, little realizing how much there was to learn from a commitment in depth to a single well-defined line of enquiry.

From the moment I became registered as an MSc student my life style changed, from fully committed participation in doing a job well, to the intense competitive business of fulfilling all the requirements and achieving the grades in a number of courses. Massler happily looked after all of that, directing me along with all his other MSc students into the right courses to attend so as to accumulate the appropriate points. He maintained a very close watch on our progress. He also kept us all on our toes by regularly demanding outlines of what we were doing and samples of our writings. By now, he would say, you should have written your Literature Review, now your Materials and Methods, and so relentlessly day by day he made his demands.

Whenever you handed Massler work, it would come back in a day or two completely edited with suggestions for additional information. Just as you thought you were getting somewhere he would suddenly ask, as he did with me, where is all the data on the premolars and molars? To what data was he referring, I wondered? Nobody had before suggested that I should look at the molars. I found that Christofferson, early in the project, had taken some radiographs of mandibles of dead animals. Although the sample was incomplete I found there were sufficient radiographs to form a reasonable sequence to make a statement about these teeth. Until then I had treated the molariform teeth as a separate matter and not part of my thesis.

Even before he asked me for that information I was working twelve hours or more a day. Towards the deadline for presenting the thesis, I was working eighteen hours a day, seven days a week. I divided the day into three parts. The first six hours of the morning were for corrections and new writing, the

second, for making tables and histograms; and the third, for preparing and assembling illustrations. By the day of my viva I had an uncontrollable right eye twitch, which would only be expected in an anxious man contemplating murder.

The viva examination

I was a bit vague about how the viva for my thesis would be conducted and was surprised to find eight very serious looking academics seated round the table. I had no idea that it was to be such a formal affair, and probably just as well. Massler was at one end and I stood at the other. It all began friendly enough and I was asked some basic questions about cattle. One of the assembled academics asked me the gestation time of a cow, and because it was coincidental with the human period of nine months, I answered without hesitation. My questioner did not want to believe me. What could I say? Fortunately the questioning went on to a more serious issue. Though veterinarians and farmers said that cattle had four pairs of incisors, the biologists knew there were only three pairs and that the last pair was incisoform canines. As I had written the thesis and constructed all my tables calling all four pairs of teeth, incisors, an argument developed between the basic scientists and the dentally qualified members of the examining board. There was a real confrontation between the opposing parties. Academics were bent on scoring off each other. Both sides were equally scornful of each other. For the last half hour of my viva, I listened alternatively to the justification of the clinicians with the firmly (and correctly) held opinions of the scientists. In the end a compromise was reached. In front of each copy of the thesis I had to write a simple foreword to say that the thesis had followed current veterinarian usage in referring to the canine tooth of cattle as the fourth incisor. Giving a reference by Loomis,[6] I was home and dry. It was Charles A Reed, associate professor of zoology, who gave me the reference and it was he who identified for me the value of chronology tables in archaeology and particularly for helping to resolve when animals were first domesticated. The assumption, when you found numbers of animals of roundabout the same age, was they had been domesticated as distinct from animals of different ages being killed in a hunt. Reed gave me a great boost when he said my chronology of cattle tooth development was a valuable landmark piece of research, with special implications for archaeology.

Publication

It was unfortunate that shortly after my viva I had to return home to England. I had to leave Massler to prepare the 'Chronology of tooth development' manuscript for publication from my thesis. It must have been a tremendous task, one that at the time I did not properly appreciate, especially

[6] F B Loomis, Dentition of Artiodactyls *Bull Geo Soc Am* 1925; 36: 583-604.

as I was accorded senior authorship.[7]. I did learn subsequently and realised how much I had to thank Massler for all he did to help me.

Conclusions

My background in orthodontics was invaluable for interpreting the sequential nature of tooth development and eruption and in recognising the synchronisation of these processes with the growth of the jaws of cattle.

I have never ceased to be amazed by nature's device for accommodating the first stages of the very large developing first incisor. The tooth formed in the thickness of the bone at a right angle to its final alignment in the mouth **(**Fig. 3). As the mandible grew by appositional growth and the incisor erupted, it rotated through a right angle into its correct alignment. I was equally impressed by the fan-like pattern of the individual trajectories of eruption of the incisors and the incisoform canine. As these teeth erupted they spaced themselves out along an ever-lengthening arc.

Working on the project raised numerous questions related to the embryology, development and growth of the jaws and the teeth, and I was constantly able to utilise my understanding of growth from my orthodontic background. When I eventually became a full-time basic science teacher I frequently used the knowledge acquired whilst working on the project.

In my subsequent research I often used exhibits to present the work in which I was involved. My experience for the exhibit made for the veterinarian conference in Philadelphia, taught me a lot about how they should be designed and constructed, as well as how they should be worded.

When I returned from the States I worked on the chronology of tooth development in pigs.[8] My concluding research papers, published after I retired in 1987 again utilise my American experience. I worked out the chronologies of tooth development, eruption and wear for Fallow deer (*Dama dama*)[9],[10] and

[7] W A B Brown, P V Christofferson, M Massler and M B Weiss, Postnatal tooth development in cattle, *Am J Vet Res* 1960; 21: 7-34.

[8] R A McCance, E H R Ford and W A B Brown, Severe under nutrition in growing and adult animals. 7. Development of the skull, jaws and teeth of pigs, *Brit J Nutr* 1961; 15: 213 -224.

[9] W A B Brown and N G Chapman, The dentition of fallow deer (*Dama dama*): a scoring scheme to assess age from wear of the permanent molariform teeth, *J Zool, Lond* 1990; 221: 659-682.

[10] W A B Brown and N G Chapman, Age assessment of fallow deer (*Dama dama*): from a scoring scheme based on radiographs of developing permanent molariform teeth, *J Zool, Lond* 1991a, 224: 367-379.

Red deer (*Elaphus cervus*).[11],[12] They have been of particular interest to Wildlife researchers.

Some personal thoughts

Before I arrived in the States I was more a careless chatterer than a conversationalist and was very undisciplined in the way I expressed my ideas. Working in America changed all that. I suspect one of the reasons was that having been so involved in one main idea for so long, I really knew more about it than most people and with Massler continually asking my views, I learned to organise and sequentalise my thoughts. He encouraged me to make presentations with the briefest of notes, saying that when I talked about the work with him I was perfectly fluent without any notes and so why shouldn't I be in public. It was with such encouragements from my two years in the States that I got the confidence to undertake a variety of projects.

Massler would often casually walk round among his students wherever they might be working and paused to see how they were getting on. He once told me how fortunate I was that I had a facility for analysing data, but also that I was able to synthesise and organise diverse information into concepts. He implied that people were more usually analysts or synthesisers, but rarely both. Massler's observations were helpful as, until he made them, I had never considered how my mind might work. I found being involved in research was a most enjoyable and interesting way of earning a living. Massler once remarked how fortunate I was that I had no personal commitments as it left me free to concentrate on the work in hand. I smiled!

With my Illinois Master's degree I was able to apply for academic jobs and increasingly distant myself from routine clinical work. On one occasion Massler had said to me that when I returned to England I should not get chained to a dental chair: I should look at several disciplines. Of course British dentistry did not work that way. Maury also said he was satisfied that I would be a good basic science researcher, but did not think that I had enough experience in clinical research.

My experience of doing research dramatically demonstrated how the process of testing a hypothesis involved an intense commitment to understanding every small and relevant fact that could possibly be related to the subject of the hypothesis.

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[11] W A B Brown and N G Chapman, The dentition of red deer (*Cervus elaphus*): a scoring scheme to assess age from wear of the permanent molariform teeth, J Zool, Lond 1991b; 224: 519-536.

[12] W A B Brown and N G Chapman, Age assessment of red deer (*Cervus elaphus*): from a scoring scheme based on radiographs of developing permanent molariform teeth, *J Zool, Lond* 1991c; 225, 85-97

I always felt that when Maury Massler seconded me to the cattle project, he gave me far more responsibility than anyone would have given me back in England. Of course he and Christofferson were there in the background and helping all the time, but I was left with the impression that I was responsible for making sure all the data was satisfactorily analysed and capable of being published.

Massler's capacity to review and edit our written work at speed left a great impression on me. You always knew that you would get your draft manuscript back within twenty-four hours, so you never lost the impetus to drive on and get finished. It was a commitment that I tried to follow with students who submitted manuscripts for my attention later in my career.

My two years in the States introduced me to formalised hypothesis testing and I learned to apply the principles I had acquired in every area of my life. Attainment of objectivity in all matters became my goal.

Unanswered questions

Years later there were still some unsolved matters with the cattle project. Why is it that though the incisors might be clearly banded by hypoplastic fluoride damage on their labial surfaces, it did not always follow that the lingual surface was equally marked. I suspect all cattle's teeth have a fine covering of cementum which gets rubbed off, especially on the labial surface of incisors, quite early after the teeth has erupted into the mouth, but at the time of writing up my thesis there was no published consensus. There was a lot more to know about the periodontal ligament attachment: first to the bone and more complexly to the attached gingiva. Tooth attachment was different in certain important aspects in the incisor region. Though we often puzzled at the absence of maxillary incisor teeth, we never reviewed the evolutionary and adaptation significance.

Summary

It was possible to examine a radiograph of an animal with developing teeth and use the chronology tables to assess age within plus or minus two months. This accuracy was tested at a Chicago stockyard show. We offered to radiograph the animals competing in the different classes. When the farmers realised how accurate we could be, many were reluctant to submit their animals for radiographing. Judges at the cattle shows apparently often doubted that the animals were correctly classed according to age and radiographing the animals would have helped to eliminate cheating. Massler was interested in exploiting the use of radiographs for ageing animals, as a possible way of earning a royalty, but for one reason and another the idea never got off the ground.

The results of our research were used in the United Steel Company’s defence against farmers suing them for damages to their livestock. Christofferson said that the forty thousand dollars that the company paid for the

research at the Illinois Dental School was one of their best investments in terms of useable evidence with which to challenge the claims of the plaintiffs.

Archaeologists working on the onset of domestication in animals recognised the value of the chronology tables in establishing the ages of animals. When I saw a slide of one of our published illustrations at a lecture given by an archaeologist in 1984, quoting "Brown *et al* " but drawing different conclusions to ours, I realised how much more work could have been done with the project.

Today the 'Chronology of tooth development' is published in all standard texts and still provides a base line for research projects. Most recently It was used to investigate the age at death of cattle recovered by archaeologists from Neolithic sites in England.

Acknowledgements

I owe Maury Massler a great debt of gratitude for his generous encouragement and for providing me in the progressive learning environment of the University of Illinois such a wonderful opportunity to learn the basics for my scientific career. There were very few similar opportunities in England at that time.

I appreciatively acknowledge that this study was supported by a generous grant from the Columbia-Geneva Division of U S Steel Corporation.