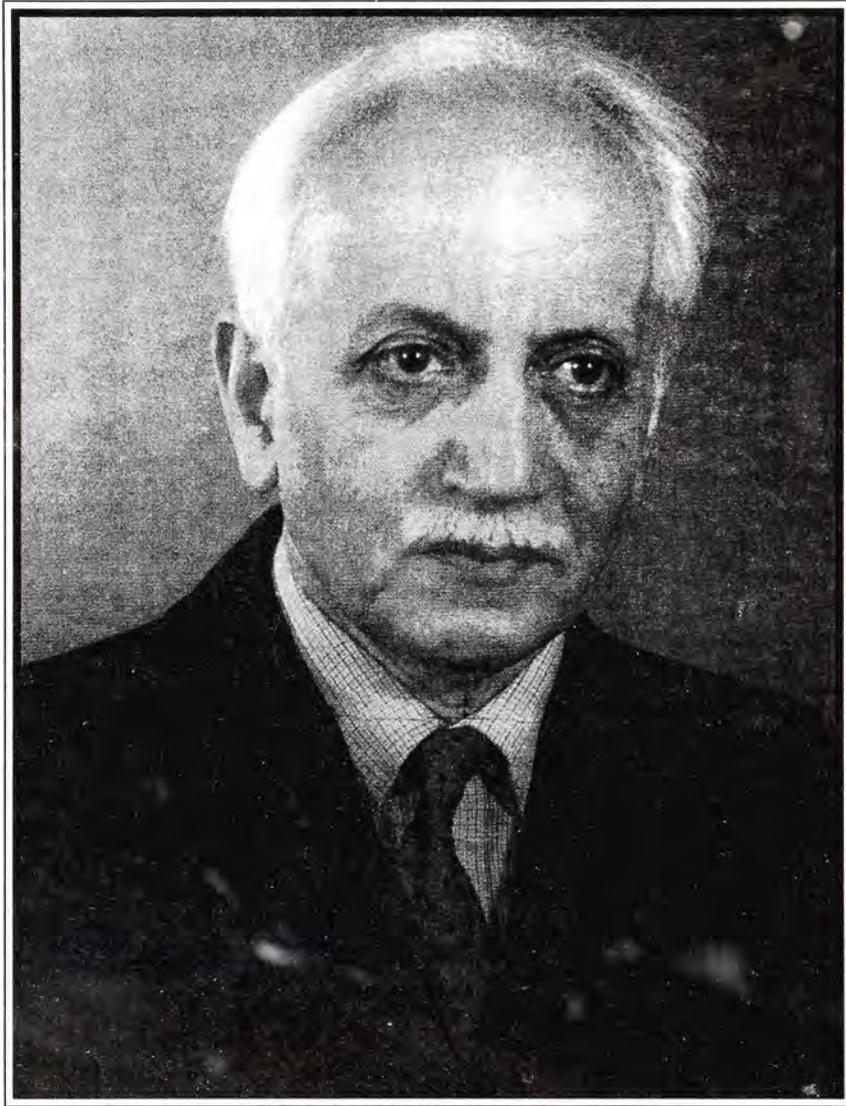


AUTAR SINGH PAINTAL
(24 September 1925 – 21 December 2004)

Biog. Mem. Fell. INSA, N. Delhi **29** 145-168 (2006)





H. S. G. S.



AUTAR SINGH PAINTAL

(1925 - 2004)

Elected Fellow 1972

AUTAR SINGH PAINTAL never left any autobiographical notes behind, but he filed all his correspondence carefully. Starting from his days in medical college, he kept a copy of nearly every letter that he wrote along with all the letters that he received. He was to benefit from being able to access these records when all else failed in times of various crises, which appeared all too frequently in his official and personal life. From this collection of letters I, who was his second wife and associate in science, learnt a lot about the man, the trials and tribulations that he underwent throughout his life. About issues that were closest to his heart, especially about the conduct and goals of scientific activity I gleaned from the animated discussions that we had almost all waking hours, when we were not occupied with experiments. Autar's father loved to talk about all events connected with his son's childhood and early career and every meeting that I had with him over a period of ten years, I learnt some more. His earliest story was, that when he forbade the four-year old young boy from throwing dirty stones down the courtyard well, since the family's drinking water came from it, he threw in his ruby ring because all he was fascinated by was the sound of the splash that arrived so long afterwards.

FAMILY BACKGROUND AND EARLY LIFE

Autar Singh Paintal was born on September 24th, 1925 in Mogok, a town in northern Burma (Myanmar), whose mines have always produced the world's best rubies. To visit it now, one requires a special permit. His father, Dr Man Singh was one of the very few surviving members of a large family who hailed from the village of Pindori Kalan, near Amritsar; most of the family was wiped out in the 'great plague' of 1903. Being orphaned at the age of seven, a paternal uncle, Dr Sundar Singh, a physician himself in Burma, brought him up and also supported him till he graduated with a licentiate degree to practise medicine, from Rangoon Medical College. Autar's mother, Rajwans Kaur was the daughter of a General in the Maharaja of Kapurthala's army. Dr Man Singh was firmly in the grips of the spirit of the times, joining the movement for independence of the country in his own way. With his unbending ways and political views he was, in his own words - "always in disagreement with his seniors". After every conflict he was posted to a new place. Although his mother felt burdened with these moves, as there were five younger children to take care of, Autar recalled the excitement of a new school every few years. Starting off to study in St Paul's in Rangoon, he then went to St Peter's in



Mandalay. Here, as a small boy football was his great passion. On our visit to this school in 2003, a year before he passed away, he was pleasantly surprised to find that the position of the goal posts was exactly where he remembered it to be. But he also never lost an opportunity to play truant and go fishing with his friends in the moat that surrounded Mandalay Palace. Invariably, he was caught and caned, as was the practise in those days and he took to wearing two pairs of shorts at the same time, to lessen the pain. This was possibly the first instance where he devised something simple to overcome a problem, a quality that was to remain with him right upto his later years. From Mandalay, the family moved to Kalaw, which is a picturesque hill station in the southern Shan States. Here, he went to Kingswood school, and was all of ten years old when he was left behind in its boarding house when his father moved back to Rangoon. He spoke good Burmese. But his mother was insistent that he also learn to read and write Punjabi or Gurumukhi. Although she had ingrained him well with the teachings of the Sikh scriptures, she wished him to read them as well. He recalled that he did learn the language, but for a price. She agreed to pay him an amount for a comic book that he had seen in a bookshop in Bogyoke Tse Scott market. The deal was struck and honoured. But at the bookshop he was literally short changed and in order to seek justice, on his way out he helped himself to a packet of old stamps that would cover the difference.

The year was 1939, and as war was imminent and a Japanese occupation likely, he was sent to an aunt in Lahore to finish his matriculation, ahead of the evacuation of the rest of the family from Burma. He was fourteen years old and studied in the Khalsa High school while his cousins went to a more fancy school. Nevertheless, he established a greater bonding with an older cousin and also his aunt who lavished great care and attention on him and which appeared to have been more so than by his own mother or his siblings. This was to remain intact upto the end of their lives. He studied hard and by this time he started to build his inexhaustible fund of limericks that he subsequently became famous for. Here, he learnt to row the large country boats that plied on the River Ravi. If there was a river in any place that he lived in thereafter, he always sought to find its boats. Later, he was to spend many an hour on the Yamuna, rowing after work on winter evenings or on the weekends.

In Lahore, he stayed on at the Forman Christian College to write the Intermediate Examination of the Punjab University (1943) after which he joined his family in Lucknow where his father had chosen to settle down.

MEDICAL COLLEGE AND POSTGRADUATE STUDIES

Admission into King George's Medical College in Lucknow in 1943 was an easy matter but he needed financial support to see him through. His father being an evacuee was in no position to help, as he even had to surrender his life insurance policies to enable him to re-establish himself and support a large family in the new



and adverse circumstances. Fortunately for him, he held the status of a 'Burmese Evacuee' and the Burmese government came to his rescue. He was always to regret that he could not serve them after completing his medical studies, because of the conditions prevailing in Burma at that time.

His student years at King George's Medical College (1943-1948) were marked by distinctions, honours and awards, finishing off with winning the coveted 'Hewitt Gold Medal' that signified obtaining the highest marks in the final MBBS examination. That, he was a serious student and committed to do well can be concluded from his having to study under the bright lamps of the 'Lucknow Residency' grounds where he sought the quiet, away from a large and noisy household. But AS Paintal was no bookworm- he and his buddies spent their leisure time rowing on the River Gomti and as amateurs became skilled enough to win awards in the annually held Regattas of Lucknow University.

But graduating in 1948 with an extraordinary brilliant record behind him, it was not surprising that he gave up a future career in clinical medicine which although would have been lucrative, but not satisfying enough for the young man, who was already evincing a keen interest in research. His father took some time reconciling to this idea and later admired him for this; his siblings however did not, advising the subsequent generation to specialize in clinical medicine instead. The Medical superintendent of King George's Medical College, while reluctantly agreeing to recommend him for an M.D. Degree in Physiology, wrote that he "was confident that he will make a valuable and useful contribution to science in course of time." His teachers too, were taken aback with this decision and SN Mathur, the Professor of Physiology recorded that, "In my life-long experience as a teacher, I have not come across another young man who, through sheer love and liking for research, has deliberately given up his clinical training for the sake of a research job".

After being appointed a Lecturer in the Physiology Department of King George's Medical College, he started to work for an M.D. degree. Dr Paintal chose a subject in Psychophysiology for his thesis and worked on the "Electrical Resistance of the Skin in Normals and Psychotics". For this he built some apparatus himself and handling it with great dexterity, collected some extraordinary data from which he devised an index which came to be referred to as the 'Paintal Index' (Ref: Elliott & Singer, *J Exp Psychol* 1953; 45: 429). Since this was independent of basal skin resistance, it assumed considerable value till more advanced methods were available to psychiatrists to diagnose psychotics.

EDINBURGH DAYS

As soon as the M.D. thesis was submitted, he proceeded to apply for a fellowship to work for a Ph.D degree with Prof David Whitteridge in the Physiology Department of the Medical School in Edinburgh. He was successful in obtaining a Rockefeller



Fellowship, but contrary to the normal practice, he did not use it in a laboratory in the USA. 'Monty', as he was known to all his colleagues during his Edinburgh days, because with his beret on, he bore an uncanny resemblance to General Montgomery (British General during World War II), was now in the midst of stalwarts in Physiology. Working with one of them- Catherine Hebb, this period was marked by an intensive study of various aspects of neurophysiology. The first of his significant findings here, was showing that 'pulmonary vascular fibres' which Whitteridge had reportedly discovered, did not exist. This was accepted graciously by the Physiological Society, UK where it was presented first and this stance was to influence him in being judicious with credit, wherever it was deserved.

The most priceless activity here, according to him was to have acquired a certain specialization in electronic engineering. He learnt to build small circuits and repair his equipment. As in his Lucknow days where he frequented the junk shops, in Edinburgh too he headed for the flea-market. From here he salvaged the wide-lens camera with which he filmed all his records right up to his last experiment in 2001. This was actually a World War II 'reconnaissance camera' which appeared to have made many a sortie over Germany. From the very beginning of his career, he had to make do with meagre resources. He made several electronic circuits all the time in his laboratory in Delhi and was able to repair his 'Beckman' and 'Grass' preamplifiers and stimulators most of the time. On a later visit to his laboratory, David Whitteridge was to remark that Paintal was probably the only Director in the world, "who wields a soldering iron". He was always in admiration of electrical engineers, who he said "are priceless people, they are like neurologists in tracking down the site of lesion". He looked upon computerized equipments, when they took over physiology laboratories, with disinterest - not being able to calibrate them and not being able to identify the source of the problem when they stopped to function. Indeed, more so because colleagues started to talk in terms of 'cleaning up their data' with the help of computers.

VALLABHBHAI PATEL CHEST INSTITUTE –THE FIRST STINT

After spending about two years in Kanpur (1952-1954) at the Technical Development Establishment Laboratories (Ministry of Defence), where his main assignment was testing of clothes and drugs for the Army and studying environmental physiology, he joined the Vallabhbhai Patel Chest Institute, Delhi University as an Assistant Director (1954-1956). It was here (1954) that his most important discovery, the J receptors, was made. He desperately wished to preserve for posterity, the bit of lung from which he had just recorded; but being able to issue out a small quantity of formalin, from the Institute's Stores, for this purpose, was as bureaucratically difficult at that time as it was later when he himself became the Director. The result seen then, was that the piece of lung had to be thrown away and that later, he



streamlined the functioning of the Institute, keeping foremost the interest of the research investigators.

USA-VISITING ASSOCIATE PROFESSOR

In the Departments of Physiology in the Medical Schools of Albert Einstein, New York, and Salt lake city, Utah he digressed for a while from his interest thus far in the cardio respiratory system, and worked on mammalian muscle. With CC Hunt in Utah, he published the term, 'fusimotor' for the nerve fibres innervating the intrafusal fibres of muscle spindles.

Although he was in his element working in laboratories abroad, yet he firmly turned down an offer of a tenure position at the Albert Einstein Medical College, citing the need of his country as foremost. No amount of persuasion, or being pointed out that "working in India will be like swimming against the tide" by his American colleagues made him ever change his mind.

ALL INDIA INSTITUTE OF MEDICAL SCIENCES— PROFESSOR OF PHYSIOLOGY

Instead, on his return as a senior faculty at the All India Institute of Medical Sciences (1958-1964), he had stalwarts in the field of physiology and medicine (Richard Riley, John Dickinson, David Whitteridge, RW Torrance, Abraham Guz, Ainsley Iggo – to name a few) come out and work with him over extended periods in his laboratory and later at the Vallabhbhai Patel Chest Institute. (See list of bibliography for publications arising from these visits).

Here, he continued to work on muscle — studying the mechanism of muscle pain. To the medical students that he taught, especially the class of 1961, "he was an enigma – brilliant fascinating, witty, explosive character with more than a trace of resemblance to the action potentials, of which he was so fond of. His excitatory threshold was low, very low –yet he acted as a source of excitation for us all. Both in his research work and his extra-curricular activities, Dr Paintal had a flair for the avant-garde. We knew that he was a famous man, a man of erudition, better appreciated abroad than at home". Although they were only undergraduate students yet they were perceptive enough to point out that, "It is therefore befitting that, a stormy-petrel should be awarded a Fellowship of the Edinburgh Royal Society, and it is no doubt ironical that the dour Scots should recognize the volatile Indian—a recognition that his own country has been tawdry in awarding".

VALLABHBHAI PATEL CHEST INSTITUTE — DIRECTOR

In 1964 he arrived once again at the Vallabhbhai Patel Chest Institute, this time as its Director; he was just 39 years old. He kept no separate office from his laboratory and



ran the Institute from within it. As a scientist-director he appreciated the needs and difficulties of other scientists and fought against the exploitation of younger scientists for building up personal reputations. He met his entire faculty at the 11'o clock coffee in the library, so that none ever found it difficult to meet him. All problems of the Institute were aired here so that it could be run in a most democratic manner. The faculty had full freedom to carry out work in whichever aspect of cardio-respiratory research they wished to undertake, as long as they were headed towards meaningful advances. He ran a journal club for the physiologists everyday, over afternoon tea.

He added a few more departments to the existing ones; the most significant being the Department of High Altitude Physiology, which he worked hard to get sanctioned from the Ministry of Health. He felt the greatest need for this, especially after seeing the supremacy and preparedness of the Chinese to combat well in high altitude areas in 1964. The war with Pakistan in 1965, re-emphasized the necessity of intensifying efforts in this sphere. The department started to grow during his tenure but was shut down after he left. He had the existing Department of Biochemicals, which manufactured antigens for desensitizing patients of allergies, upgraded into a Centre which he then transferred to the Council of Scientific & Industrial Research (CSIR), so that it could expand its activities adequately. This now has been transformed into the CSIR's Institute of Genetics & Integrative Biology & Functional Genomics, but it still manufactures the antigens that it had set out to do. In 1985, he took leave from the Institute to work as the Director-General of the Indian Council of Medical Research. A position at which he remained for 5 years and till he was 66 years old.

SCIENTIFIC CONTRIBUTIONS

Autar Paintal was recognizably a first-rate scientist with a strong sense of where he wanted to go and how to achieve his aims. He was certainly the leading neuroscientist of his generation in India; and was largely responsible for bringing new standards of excellence to the Neurosciences in India.

One of the most insightful scientists of the world in the field of Physiology, his contributions came to be described as having opened a new phase in Physiology with the Nobel Laureate Corneline Heymans and Eric Neil coining the term 'Pre-Paintal era' versus 'Post-Paintal era' while referring to the impact of his discoveries. Apart from the earlier work by Gaskell & Langley and later, by Dale, Loewi & Hess, his contributions can be considered to be the most significant in the field of visceral control mechanisms. This was made possible by the introduction by him, in 1951, of methods for dissecting and recording impulses in individual sensory fibres and measuring their conduction velocities. He also achieved this by taking the bold step of discarding the well-established technique of the great masters at Oxford and



Cambridge, of dissecting nerve fibres under saline and recording impulses from them in air. Instead he developed a technique for dissecting thin nerve filaments from nerves under liquid paraffin and showed contrary to the conclusions of Brown & Pascoe (*J Physiol* 1951; **114**: 16P) that dissection under liquid paraffin was possible and was easy, and that from such filaments normal-sized impulses could be recorded from individual nerve fibres. This technique was rapidly adopted in the laboratories of UK and USA.

A second important technical advance made by him was the introduction of a technique of proving the conduction velocities of individual fibres in multifibre preparations. Both these techniques were published in the *Journal of Physiology*. He also showed that using the same technique it was possible to dissect and record impulses in the slowest conducting fibres with conduction velocities of 2 m/sec i.e. non-medullated fibres. This work was extended by Iggo (*J Physiol* 1958; **142**: 110-126).

A third technical advance made by him was the introduction of a technique for locating visceral receptors by injecting excitatory substances, notably phenyl diguanide. With the use of the above techniques, he made the following discoveries and contributions:

(a) *Discovery of the Type B Atrial Receptors (volume receptors) 1952*

This historical discovery was made by him while he was still in Edinburgh. Soon it was to become the basis for the fluid regulation hypothesis of Henry & Gauer. That there is a fluid regulating reflex originating from these receptors in the left atrium, was confirmed by others, notably by the group in Leeds. Indeed, in their monograph entitled- 'Atrial Receptors' published in 1982, Linden & Kappagoda proved that the reflex increase in heart rate and the reflex increase in urine outflow, obtained by distending the left atrium, are due to the stimulation of Paintal's volume receptors. By establishing the basic properties of these cardiac vagal afferent fibres he provided a firm foundation for studies of central cardiac reflexes, by a generation of physiologists.

(b) *Discovery of the Gastric Stretch Receptors 1953*

These receptors, which are the mechanism for the immediate satiation of hunger and thirst were discovered by him in 1953, and were at first reported in *Nature* and published in detail in 1954. With this discovery he opened up the field for the study of the electrophysiology of sensory mechanisms of the gastro-intestinal tract. Soon, in his steps and using his techniques followed the work of Iggo, Leek and later that of Mei. Later, according to him the discovery of the gastric stretch receptors did not appear to be glamorous enough, yet this seemed to have given him the momentum that culminated in subsequent discoveries.



(c) *Mucosal Mechanoreceptors of the Intestines*

These were discovered in 1957 by him and he showed that they were mechanoreceptors located in the mucosal layers of the small intestines. They were distension-sensitive and were not stimulated by contractions *per se* of the small intestines. He concluded that these endings were located in the plane of the villi and that their function was to signal the presence or passage of intestinal contents.

(d) *Discovery of Ventricular Pressure Receptors*

In 1955, he reported the discovery of the ventricular pressure receptors and demonstrated with observations and arguments that these receptors constituted the mechanism of the Bezold-Jarisch reflex. This paper has now become a classic (see, Fishman, 1964) and has been reprinted by Dowdon, Hutchison & Ross (1976) under the Benchmark Series as one of the classical papers in cardiovascular physiology.

(e) *Pressure-Pain Receptors in the Muscles*

By carrying out a functional analysis of Group III afferent fibres of mammalian gastrocnemius, soleus and tibialis muscles, he established that the majority of the sensory fibres of this group terminate in pressure receptors and very few do so in stretch receptors and in very few could impulses be aroused by mechanical stimuli. His results suggested that this group of receptors may mediate the sensation of muscle pain produced by squeezing the muscle, although not be responsible for the muscle pain of ischemia.

(f) *Contributions to the Understanding of Chemoreceptor Mechanisms*

Corneille Heymans was awarded the Nobel Prize for demonstrating the role of the aortic and carotid chemoreceptors in the stimulation of respiration. Paintal's contribution in this field have been significant for he cleared certain misconceptions that existed, e.g. the existence of a metabolite and the belief that the chemoreceptors were not stimulated by anaemic hypoxia. He showed that the actual stimulus for the chemoreceptors was reduced oxygen availability, which determines the local tissue pO_2 at the receptors. He also showed that CO_2 does not stimulate the aortic chemoreceptors and that local mechanical interference in the vicinity of the receptors stimulates them. With Anand, he showed that altering the external environment of the chemoreceptors affects the activity of aortic chemoreceptors. This has been confirmed by others and therefore on account of this work on aortic chemoreceptors it has become necessary to re-evaluate all the previous work on carotid chemoreceptors and the reflex effects produced by them as in their case the exposure of the carotid body and interference in this region is avoidable.



(g) *The J Receptors*

In 1955, Paintal published the existence of certain endings that were stimulated by injections of phenyl diguanide into the right atrium and were stimulated by pulmonary congestion. At that time he called these endings deflation receptors and demonstrated that they reflexly caused bradycardia, hypotension and tachypnoea. In a subsequent paper, he located these endings distal to the respiratory bronchioles.

Twelve years later, he published his third paper on these receptors wherein he proved that the endings must be located in the interstitial tissue in juxtaposition to pulmonary capillaries and the alveoli. He therefore called them juxta-pulmonary capillary receptors i.e. type J receptors (currently J receptors). The location of the endings was established from precise measurements of latencies for excitation of the endings by volatile anaesthetics. However, the most notable part of this work consisted of new observations on the responses of these endings during pulmonary congestion. He showed that no matter how the congestion was produced, whether by increase in back pressure in the pulmonary circulation or by a combination of increase in pulmonary capillary pressure and increased permeability of the capillary wall, the result was the same, i.e. an increase in the activity of the endings. As a result of these observations he postulated that these endings must be located in the collagen tissue in the interstitium and that the swelling of this collagen due to an increase in the outflow of fluid as a consequence of increase in pulmonary capillary pressure caused the excitation of the receptors. These conclusions have received substantial support from electromicroscopic studies of Meyrick & Reid (*Respir Physiol* 1970; **11**: 366-377) and Hung et al. (*Am J Anat* 1972; **135**: 477-490), showing their existence in the precise location predicted by him. In 1980, these were also reported in the human lung of man by Fox, Bull & Guz (*J Anat* 1980; **131**: 683-692).

(h) *The J reflex (Termination of Exercise: Muscle Weakness)*

Paintal concluded that the endings must be stimulated during muscular exercise which produces obvious increase in pulmonary vascular pressure particularly when exercise is done at higher altitudes (e.g. at 3,000 metres). From the absence of reflex cardiovascular adjustments that could reduce reflexly the activity of the receptors, he concluded that stimulation of these receptors must lead to reflex termination of exercise so that muscle pump is shut off providing a protective reflex to humans and animals against excessive pulmonary pressures. Indeed, experiments done by him and his co-workers Deshpande & Devanandan (*J Physiol* 1970; **106**: 345-357) and Kalia (*Pflugers Arch* 1973; **343**: 297-308), clearly established the existence of this reflex whose integrity involved higher centre (Kalia, 1973). Subsequently, in experiments with Koepchen and Kalia in Berlin it was demonstrated in conscious unrestrained cats that they stop moving when the receptors are stimulated suddenly. Later his students, Ahluwalia & Rao working in his laboratory showed that the spinal pathway involved was located ipsilaterally in the ventro-medial part of the spinal



cord (Paintal AS, Gill, Kumar, editors. *Respiratory Adaptations, Capillary Exchange & Reflex Mechanisms*. Delhi: Vallabhshai Patel Chest Institute 1977). The J reflex is a protective reflex that prevents the occurrence of pulmonary oedema by shutting off the muscle pump and it is obviously so in cases suffering from pulmonary congestion, heart failure, mitral stenosis and at high altitude. He described the reflex termination of exercise as one of their most important functions. In human studies, the H (Hoffman) reflex was studied at par with the J reflex. These were carried out by Dr Hans Raj, using the soleus H reflex (monosynaptic reflex) as an equivalent of the J reflex, Raj & Aggarwal (1998) found a considerable reduction in the amplitude of the H reflex in response to lobeline i.v. Thereafter, he and his group also undertook to study the influence of natural stimulation of J receptors on the amplitude of the H reflex. This was achieved by accumulating blood peripherally by applying lower body negative pressure (LBNP) and then suddenly releasing it, by which manoeuvre about a litre of blood is added to the central circulation and leads to an acute increase in cardiac output. This, thus mimics the cardiovascular events of exercise, which then can be studied in the absence of confounding influences from limb sensory receptors. Results obtained showed a reduction in the amplitude of the H reflex concomitant with the sudden release of peripherally accumulated blood into the central circulation. These results were sent by us to be communicated to the XXXVth Congress of the International Union of Physiological Sciences (IUPS), 2005 and were subsequently presented by me.

(g) *Breathlessness*

The stimulation of J receptors by a rise in the interstitial fluid volume and increase in pulmonary blood flow (in left heart failure; coronary artery disease; chronic obstructive pulmonary disease) also gives rise to breathlessness. We showed that these receptors are also stimulated by increased blood flow, as in exercise. Along with his other collaborators— he showed that stimulation of J receptors produced respiratory sensations in the throat and upper chest and dry cough. This discovery has assumed significance clinically in patients experiencing dry cough and especially after showing the presence of lobeline-induced cough in anaesthetized and unconscious patients.

Both of us continued to contribute to this field and in the early nineties discovered the principle relating to the relative dilution of multiple solutes in flowing fluids. Using this principle we introduced a new method for measuring *in vivo* the blood concentration of injected drugs and devised a method for detecting early changes in pulmonary capillary permeability, which would have a great application potential in humans, during 'acute respiratory distress syndrome' (ARDS). That this breathlessness can be eliminated by cutting the nerve fibres arising from these receptors i.e. by vagotomy or by vagal block in certain cardio-respiratory conditions has already been shown to be effective in the clinics in the west. Extensive



observations by others confirmed this discovery. Nonetheless, along with his colleagues, he kept seeking newer information as to how to approach the problem, and a recent one was the demonstration of respiratory reflexes and sensations arising by stimulating J receptors in normal subjects, patients with cardiological problems and those unable to perceive sensations.

The last few studies that he was involved in were to demonstrate the application of the above knowledge for reducing the disabling consequences of exertion or exercise, in patients with cardio respiratory disease. In this regard further insight was also to be sought into the role of J receptors in termination of exercise (exhaustion or fatigue).

DST CENTRE FOR VISCERAL MECHANISMS

Based on his discoveries, the Department of Science & Technology set up a Centre for Visceral Mechanisms so as to intensify and extend the work on dyspnoea (breathlessness) and exercise limitation that arise reflexely by stimulation of J receptors. The aim was to study the pathway involved to be able to find palliative measures of *reducing the distressful breathing* experienced by patients of restrictive lung diseases and by soldiers at high altitude and *to decrease muscle weakness/ increase the limited exercise* that is only possible. The DST continued to fund this research of national importance, thereby also giving international visibility to India's contribution to the field of problem-solving medical research. Having discovered the pathways involved, current research being carried out from this laboratory is concentrating on identifying measures for reducing breathlessness.

FELLOWSHIPS OF LEARNED BODIES AND AWARDS

The science academies of India were not to be familiar with the impact of Paintal's contributions to Physiology till many years after they were made. The Royal Society of Edinburgh was the first to elect him to its fellowship in 1966 and the National Academy of Medical Sciences (India) soon followed. He was elected to the fellowship of the Indian National Science Academy eight years later in 1972.

In 1981, his election to the Royal Society, UK made him the first Indian Medical Scientist to belong to its Fellowship.

STUDENTS AND COLLEAGUES

To each of his students he gave one receptor that he had discovered, to work on for their PhD or MD thesis. After that, as postgraduate students or as junior faculty in the Institute, they were free to continue working on these and furthering knowledge. But, if they went on to work along different avenues especially after their post-doc stints abroad where he sent them, or if they subsequently disagreed with his earlier conclusions, he found no reason to impose his will on them. Apart from discussing



problems that they brought to him themselves, he made sure that he did not even appear to interfere with their newer lines of work.

To Dr Senapati, he gave the pressure-pain receptors; he worked on their reflex effects and was the first to discover that stimulation of these receptors causes reflex increase in ventilation and were therefore partly responsible for the increased breathing during muscular exercise. Marcus Devanandan, who later became the Professor of Physiology at the Christian Medical College, Vellore, validated along with Sharad Deshpande, his hypothesis that the stimulation of J receptors leads to inhibition of muscles. To Madhu Kalia, he gave to extend the work on the J reflex and its central connections. She established the role of higher centres of the brain in the reflex inhibition work that she carried not only at Vallabhbhai Patel Chest Institute but also with his associates — Professor Whitteridge, at Oxford and Professor Koepchen, at Berlin. P Sheshagiri Rao worked on pulmonary stretch receptors; Mohammad Fahim worked on Atrial Receptors. To me, was given the task of reinvestigating the natural stimuli of aortic chemoreceptors; to K Ravi, the location of the two types of pulmonary stretch receptors. Dr Hans Raj worked on human subjects, on the somatic and respiratory reflex effects of J receptors. Finally, he found training any more PhD students a waste of Indian research funds and his time because he saw them drifting away to laboratories overseas.

ETHICS IN THE CONDUCT OF SCIENTIFIC PURSUIT (SOCIETY FOR SCIENTIFIC VALUES)

In the mid-nineteen seventies, when various cases of scientific misconduct in India began to be written about in science magazines such as the 'New Scientist', he became acutely concerned about the obviously declining standards of scientific ethics amongst Indian scientists. He started to voice his concern about this and the lack of goals and absence of accountability in Indian research activity. In 1985, after having conducted several rounds of discussions, he and several others who were similarly distressed by the situation in the country, founded the Society for Scientific Values.

This was the first of its kind in the world and its presence made the International Council of Scientific Union, acutely aware of the necessity to direct Academies that adhered to it, to have sections in their organizations to set down similar guidelines.

HIS PHILOSOPHY ABOUT PROGRESS OF RESEARCH AND GOALS IN SCIENCE

In his own work, he seemed to follow Pavlov's style of a gradualness of advancement in scientific knowledge. He looked deeply at his own and others' data before making conclusions; he never rushed off to talk about his results, no matter



how long it took to publish them. He held extrapolating from one set of observations to another, in complete abhorrence.

He was modest, simple and wasn't capable of unravelling cryptic remarks-you had to state everything to him as it was, for him to appreciate its impact. In personal matters he was incompetent in reading between the lines. He never sought publicity for himself, yet he put in as much effort that he could to highlight, nationally and internationally, what ever was India's contribution in his own field. He was appalled to find that the number of citations that a publication receives was being used as a criterion of achievement in Science. I quote from one of his hand-written notes on this subject. "This has had an adverse effect by reducing discoveries and advances. Many scientists do not have goals relating to making of discoveries or making inventions or trying to apply Science for social needs. One gets the impression that Scientists are not unhappy on account of not having made an important discovery. They are happy because their papers are being cited in peer-reviewed journals. Citations can be considered as being equivalent to the ovation given to performing artists, such as musicians. Can the intensity of such ovations (i.e. number of people clapping) be considered as the brilliance of the music composition itself?"

FAMILY

Autar and I married in 1988 and remained associates in science as well. His first marriage (1949) had ended in a divorce in 1985. The three children that were born out of it were literally brought up by him in his laboratory. Taking care of their various interests while they were growing up, he let them have a complete run of the place. They would drift in with their project works or their queries and had access to him, his colleagues and associates all the time. The eldest child, a daughter Anita, also specialized in Physiology and followed a research career while at UK and USA, but gave it up on her return to India in preference to teaching the subject in a medical college in Mumbai. The second, Priti has been residing in London for more than two decades and composes fusion music. The youngest, a son, Gautam studied Geology in Manchester from where he obtained a Ph.D degree and specialized as a Reservoir Geologist. He lives with his wife Stephanie and son Ravi in Lincolnshire.

LEISURE TIME ACTIVITIES

There were no distinct work and relaxation phases in his life. Total absorption in his work led to the exclusion of most activities of a social nature. National days were celebrated, but not any of the Indian festivals. This was once brought to his notice by a couple of neighbourhood children who voiced their dismay when they came to greet him one Diwali evening, and found him bent over a magnifying glass, looking



at some records that had been perplexing him. Holidays and weekends saw him either repairing his equipment or getting it ready for the next experiment or saw him clattering on his 'Olivetti' drafting letters and manuscripts or getting some new 'ideas' straightened out. He spent his free time during out-of-town meetings, poring over the filmed records, which he always carried with him.

He had been a movie buff since his Lucknow days, and in the seventies when they stopped importing them into the country, he would always 'fill himself up with the newer ones' on his visits abroad. Till his wide and rare collection of western classical music was available to him, he enjoyed listening to it, especially after work and while 'doing his office files', and he always found it a great sport, being asked to identify, the names of composers of music pieces that were presented to him, and being able to identify them correctly.

Since both of us were avid bird watchers, in the winter months we would pack a picnic and take ourselves out for a day's rowing on the river Yamuna. Any visiting friends or scientists who enjoyed this sport were also huddled out on these expeditions. These events became more or less occasions for discussing the previous day's experiment as well as being able to increase the count of the various water-birds that one saw. He was a keen swimmer, swimming not only throughout summer but also in barely-heated pools in the winter, wherever he could find them. He was still swimming in the summer, a few months before he passed away.

LAST FEW YEARS

"Let nature take care of it", this was his well known medical advise that he scrupulously followed himself and gave to others whenever consulted. So to deal with hypertension, of which there was a strong family history — he lived on a salt-free diet and no medication for two decades. This accompanied by undertaking regular exercise e.g. swimming, even in the winter months, he had hoped that would take care of it completely. It was only after the occurrence of an episode of acute hypertension about six years before his demise that he started taking medications regularly for it. About this time, his gait became rather uneven, and when pointed out to him, he said it was due to apoptosis of his motor cortical cells. "There is nothing we can do about it- it's the process of ageing, you know!" In his inimical style, he refused any help or aid or walking-stick, pushing away with great vigour, any hand that was offered to help. He continued to travel alone at home and abroad for meetings and conferences, attending his son's wedding in the UK on one such occasion. About three years before he passed away, i.e. in January of 2002, one morning, he fell down in the bathroom. Back from hospital after three weeks, he was once again unstoppable at work. Two months later he delivered the 1st GB Jain Pawan Kumari Jain Oration of the Delhi Medical Association and in September



year we travelled to Kuala Lumpur, where he delivered a special Guest lecture to the Physiologists of the Asian & Oceanian countries (FAOPS). In November, of that same year he delivered the JL Nehru's Birth Centenary Oration, of the Indian Science Congress Association. "Rivalry and Romance in Science"- in which he reminisced about how our work had progressed amidst agreements and disagreements, especially with colleagues from overseas. However, his favourite topic of talk and discussions by this time had become the pursuit of ethics in the conduct of science. He not only talked about it to the Association of Physiologists and Pharmacologists in their Annual meeting in December that year in Lucknow but also to the Iranian Physiologists in Tehran the following year (2003). He also spoke about this with great gusto to the 14th Assembly of TWAS, when invited to reminisce as a founder member at its meeting in October 2003 in Beijing. But the desire to be not too far away from the bench was unabated.

In January 2004, we travelled to Bangalore to the Institute of Aerospace Medicine to conduct one of our studies. The summer was spent analyzing these results as we intended to present them at the forthcoming International Congress of Physiology (XXXV IUPS), at San Diego. Undaunted as ever, he persuaded me to deliver an INSA Oration later that year in Srinagar, Kashmir. Perhaps he wanted to mark it as the 30th anniversary of the time that he had organized two marvellous International Symposia in Srinagar that were satellites of the 24th Congress of the International Congress of Physiological Sciences (IUPS) Delhi. Our work by now having progressed from observations in animals to validating the hypothesis (about the role of J receptors in breathlessness and muscle weakness) in humans that he had put forward in the late 70's.

A short visit to Colombo in November, to the Sri Lankan Physiological Society, was apparently to be the last of his travels but he was back, ready to welcome the participants of an International Symposium (December 6th, 2004) organized by me on behalf of the Indian National Science Academy, to celebrate 50 years of India's discovery - the discovery of J receptors. This symposium also enabled his group and the Defence Laboratories, to present their new work on the understanding and management of dyspnoea to international peers. Pride for India meant everything to him.

Two weeks later on December 21st, 2004 he passed away after a heart attack.

Four decades ago, a young undergraduate at the All India Institute of Medical Sciences had written, "such men attain their apotheosis not in spite of, but because of themselves; and add to the long scroll of humanity's achievements in the quest for eternal values and eternal truth". Autar Singh Paintal had derived his spiritual satisfaction, his search for truth in the pursuit of his science.



AWARDS AND HONOURS**(a) Policy-making Bodies**

Member Council, International Union of Physiological Sciences	1997-2001
Member IUPS Commission on Somato-sensory Physiology.	2001-2005

(b) Honorary Degrees

D.Sc. (hc) from Universities of Benaras Hindu ; Delhi; Aligarh Muslim; Patiala; Punjab; Lucknow

(c) Learned and Professional Societies: Fellow, Royal Society (London); Indian National Science Academy; Royal Society (Edinburgh); Founding Fellow, TWAS; National Academy of Medical Science (India); Indian Academy of Sciences; Punjab Academy of Science & Technology; Hony. Member, Physiological Society (UK); Hony. Member, American Physiological Society; Foreign Member, Russian Academy of Science; Founder Member (First President) Society of Scientific Values;

President: Indian National Science Academy (1987-88)

(d) Padma Vibhushan (1986)

Shakuntala Devi Amir Chand (ICMR) 1956; Basanti Devi Amir Chand Prize (ICMR) 1957; Dr BC Roy National Award (1973) and Silver Jubilee Research Award (1979) (both of Medical Council of India); Barclay Medal (Asiatic Society (1982); Rameshwardas Birla National Award (1982); First Jawaharlal Nehru Award in Science (1983) (Madhya Pradesh Government); Silver Jubilee Award (1986) (AIIMS); Ashutosh Mookerji Medal (1995) (Indian Science Congress Association); CV Raman Oration (1995) (INSA); Sir Ganga Ram Medal (1998) Jawaharlal Nehru Birth Centenary Award (Indian Science Congress Association (2002); OP Bhasin Award for Science & Technology (2002)

(e) Orations

Basanti Devi Amir Chand Prize Oration (1968); Indian College of Allergy and Applied Immunology Oration (1969); Sarabhai Oration (1970) (Association of Physicians of India); Sri Ram Oration (1973) (NAMS); Dr BC Roy Oration (1974); Chandy Oration (Neurological Society of India) (1978); Silver Jubilee Research Award Oration (1979) (MCI); Warner Oration (1981) (National College of Chest Physicians); Sharpey-Schaeffer Lecture (Physiological Society U.K.) (1980) (Edinburgh); Nayudamma Science Foundation Lecture (1982); NAMS Oration (1982); Dr Raju Oration (1982) (Pharmacological Society of India); Ranbaxy Oration (1985); First Brig. Mazumdar Memorial Lecture (1987); JC Bose Memorial Lecture (1989); V Ramakrishna Memorial Lecture (1998)



KN Senaviratne Memorial Lecture (1990) (Colombo); First R Vishwanathan Memorial Lecture (1991); CV Raman Award Lecture (1995) (INSA); First Kottegoda Memorial Lecture (1996) (Colombo); Sir Ganga Ram Oration (1998) and Jawaharlal Nehru Birth Centenary Award Oration (2002) (ISCA).

Res:
N-3, Riviera Apartments
Mall Road
Delhi-110 054

ASHIMA ANAND, FNA
DST Centre for Visceral Mechanisms
Principal Scientific Officer
Vallabhbhai Patel Chest Institute
Delhi University
Delhi-110 007
E-mail: visc.mechs@mail.com

BIBLIOGRAPHY

- 1951 A comparison of the galvanic skin responses of normals and psychotics *J Exp Psychol* **41** 425-428
- 1952 Conduction velocity of single respiratory and cardiovascular afferent fibres in the cervical vagus *J Physiol* **117** 40-41
- 1953 Another atrial receptor *J Physiol* **119** 10-11
- A study of right and left atrial receptors *J Physiol* **120** 596-610
- The response of pulmonary and cardiovascular vagal receptors to certain drugs *J Physiol* **121** 182-190
- The conduction velocities of respiratory and cardiovascular afferent fibres in the vagus nerve *J Physiol* **121** 341-359
- (With MOTE JC) The action of 5-hydroxytryptamine on pulmonary and cardiovascular vagal afferent fibres and its reflex respiratory effects *Br J Pharmac Chemother* **8** 238-241
- Impulses in vagal afferent fibres form stretch receptors in the stomach and their role in the peripheral mechanism of hunger *Nature Lond* **172** 1194-1195
- 1954 A method of locating the receptors of visceral afferent fibres *J Physiol* **124** 166-172
- A study of gastric stretch receptors Their role in the peripheral mechanism of satiation of hunger and thirst *J Physiol* **126** 255-270
- The response of gastric stretch receptors and certain other abdominal and thoracic vagal receptors to some drugs
- 1955 Impulses in vagal afferent fibres form specific pulmonary deflation receptors The response of these receptors to phenyl digunaide potato starch 5-hydroxytryptamine and nicotine and their role in respiratory and cardiovascular reflexes *Q Jl exp Physiol* **40** 89-111
- A study of ventricular pressure receptors and their role in the Bezold reflex *Q Jl Exp Physiol* **40** 348-363
- 1956 A method of recording the pulmonary circulation times in the cat In *Proceedings of the International Conference on the Peaceful uses of atomic energy* **12** 278-280 New York United Nations
- 1956 Excitation of Sensory receptors in the Thoracic and abdominal Viscera *Abstr XX Int Physiol Cong* 78-79



- 1957 The location and excitation of pulmonary deflation receptors by chemical substances *Q Jl exp Physiol* **45** 57-71
- 1957 The influence of certain chemical substances on the initiation of sensory discharges in pulmonary and gastric stretch receptors and atrial receptors *J Physiol* **135** 486-510
- Response form mucosal mechano-receptors in the small intestine of the cat *J Physiol* **139** 353-368
- 1958 (With HUNT CC) Spinal reflex regulation of fusimotor neurones *Fed Proc* **17** 75
- (With HUNT CC) Spinal reflex regulation of fusimotor neurones *J Physiol* **143** 195-212
- Intramuscular propagation of sensory impulses form stretch receptors of the cat *J Physiol* **145** 7-8p
- 1959 Intramuscular propagation of sensory impulses *J Physiol* **148** 240-251
- Facilitation and depression of muscle stretch receptors by repetitive antidromic stimulation adrenaline and asphyxia *J Physiol* **148** 252-266
- 1960 Functional analysis of group III afferent fibres of mammalian muscles *J Physiol* **152** 250-270
- 1961 Participation by pressure-pain receptors of mammalian muscles in the flexion reflex *J Physiol* **156** 498-514
- 1962 Responses and reflex effects of pressure-pain receptors of mammalian muscles In *Muscle Receptors* ed Barker D PP 133-142 Hong Kong Hong Kong Univ Press
- Determination of intrathoracic conduction time in cardiovascular afferent fibres of the vagus nerve *J Physiol* **163** 222-238
- 1963 Vagal afferent fibres *Erqgbn Physiol* **52** 74-156
- Natural stimulation of type B atrial receptors *J Physiol* **169** 116-136
- 1964 Effects of drugs on vertebrate mechanoreceptors *Pharmac Rev* **16** 341-380
- 1965 Block of conduction in mammalian myelinated nerve fibres by low temperatures *J Physiol* **180** 1-19
- Effects of temperature on conduction in single vagal and saphenous myelinated nerve fibres of the cat *J Physiol* **180** 20-49
- 1966 The influence of diameter of medullated nerve fibres of cats on the rising and falling phases of the spike and its recovery *J Physiol* **184** 791-811
- Re-evaluation of respiratory reflexes *Q Jl exp Physiol* **51** 151-163
- (With RILEY RL) Responses of aortic chemoreceptors *J appl Physiol* **51** 151-163
- 1967 Mechanism of stimulation of aortic chemoreceptors by natural stimuli and chemical substances *J Physiol* **189** 63-84
- (With ROSENBERG ME) Cooling nerves *in vivo* *J Physiol* **189** 6-8
- A comparison of the nerve impulses of mammalian non-medullated nerve fibres with those of the smallest diameter medullated fibres *J Physiol* **193** 523-533
- 1968 The possible influence of the external environment on the responses of chemoreceptors In *Arterial Chemoreceptors* (Ed RW Torrance) 149-151 Oxford Blackwell
- Some considerations relating to studies on chemoreceptor responses In *Arterial Chemoreceptors* (Ed RW Torrance) 253-260 Oxford Blackwell
- Respiratory reflex mechanisms and respiratory sensations *Indian J Med Res* **56** 1-11



- 1968 (With DICKINSON CJ) Stimulation of lung deflation receptors by the injection of carbon dioxide gas into the right ventricle *J Physiol* **196** 70-71
- 1969 Mechanisms of stimulation of type J Pulmonary receptors *J Physiol* **203** 511-532
- Further evidence that acetylcholine is not a transmitter at chemoreceptors *J Physiol* **204** 94-95p
- 1970 High altitude disabilities *Science Reporter* **7** 308-311
- (With DICKINSON CJ) Stimulation of type – J pulmonary receptors in the cat by carbon dioxide *Clin Sci* **38** 33
- The mechanism of excitation of type J receptors and the J reflex in *Breathing Ciba Foundation Haring-Breuer Centenary Symposium* (Ed R Porte)r 59-71 London Churchill
- 1971 Are chemoreceptors mechanoreceptors ? *Proc Ind Sci Cong Assoc Part IV* 137-138
- Action of drugs on sensory nerve endings *An Rev Pharmac* **11** 231-240
- The J reflex *Proc Int Union Physiol Sci* **9** 79-80
- The responses of chemoreceptors at reduced temperatures *J Physiol* **217** 1-18
- Cardiovascular receptors In *Handbook of Sensory Physiology* **111** (Ed E Nail) 1-45 Berlin
- 1972 Transmission of sensory information at the periphery *Proc Australian Physiol Pharmac Sec 3* (Special number of regional meeting of IUPS Sydney) 2-9
- Sensory mechanisms involved in the Bezold-Jarish effect *Proc Australian Physiol Pharmac Sec 3* (Special number of regional meeting of IUPS Sydney) 44-45
- 1973 Vagal sensory receptors and their reflex effects *Physiol Rev* **53** 159-227
- Sensory mechanisms involved in the Bezold-Jarisch effect *Aus J Exp Biol Med Sci* **51** 3-15
- Conduction in mammalian nerve fibres In *New Developments in Electromyography and clinical neurophysiology* **2** (Ed JE Desmedt) 19-41 Basel Karger
- (With DAMODRAN VN and GUZ A) Mechanism of excitation of type J receptors *Acta Neurobiol Exp* **33** 15-19
- (With KALIA M and KOEPCHEN HP) Somatomotor and autonomous effects of type-J receptor stimulation in awake – freely moving and unrestrained cats *Pflugers Arch Ges Physiol* **335** R 80
- (With KALIA M and KOEPCHEN HP) Motor behavioural responses to J receptor stimulation in an awake walking cat – a film recording *Pflugers Arch Ges Physiol* **385** R 80
- 1974 The identification of the origin of activity with a cardiac rhythm in the brain stem In *Central rhythmic and regulation* ed Uback W and Koepchen HP Stuttgart Hippokrates Verlag 255-259
- Fluid pump of type J receptors of cats *J Physiol* **238** 53-54
- Observations of relevance to theories of chemoreceptors excitation *Proc Int Union Physiol Sci* **9** 238
- 1976 Mechanical transmission of sensory information at chemoreceptors In *Morphology and Mechanisms of Chemoreceptors* (Ed AS Paintal) 121 129 Vallabhghai Patel Chest Institute, Delhi
- 1976 The effects of reduction of temperature on the responses of aortic chemoreceptos during administration of carbon monoxide In *Morphology and mechanisms of chemoreceptors* ed Paintal A S pp 335-339 Delhi; Vallabhghai Patel Chest Institute
- *Morphology and mechanisms of chemoreceptors* Delhi; Vallabhghai Patel Chest Institute



- 1976 Natural and paranatural stimulation of sensory receptors *In Sensory functions of the skin* ed Zotterman Y pp 3-12 Oxford Pergamon Press
- 1977 Thoracic receptors connected with sensation *Br med bul* **33** 169-174
- Effects of drugs on chemoreceptors pulmonary and cardiovascular receptors *Pharmac Ther* **B 3** 41-63
- Electrophysiology of visceral receptors *Proc Int Union Physiol Sci* **12** 84-85
- The nature and effects of sensory inputs into the respiratory centres *Fed Proc* **30** 2428-2432
- A functional estimate of the local PO₂ at aortic chemoreceptors *In Chemoreception in the carotid body* (Eds H Acker, S Fidone, D Pallot, C Eyzaguirre, DW Lubbers & RW Torrance) 250-255 Berlin Springer-Verlag
- (With GILL KUMAR P) *Respiratory adaptations capillary exchange and reflex mechanisms* Vallabhbai Patel Chest Instiute, Delhi
- (With IGGO A) The metabolic dependence of cutaneous cold receptors *J Physiol* **272** 40-41p
- 1978 Conduction properties of normal peripheral mammalian axons *In Physiology and Patho biology of axons* (Ed SG Waxman) 131-144 New York Raven Press
- 1979 (With ANAND A and IGGO A) Lability of granular vesicles in Merkel cells of the type I slowly adapting cutaneous receptors *J Physiol* **296** 19p
- Electrophysiology of atrial receptors *In Cardiac Receptors* (Ed R Hainsworth, C Kidd and RJ Linden) 73-86 London Cambridge University Press
- 1980 The regulation of food intake in *Scientific Foundations of Gastroenterology* (Ed S Sircus and AN Smith) 123-129 London William Heinemann Medical Books Ltd
- (With ANAND A) Reflex effects following selective stimulation of J receptors in the cat *J Physiol* **299** 553-572
- Visceral sensory mechanisms and sensations – Introduction *Proc Int Union Physiol Sci* **14** 212
- (With ANAND A and IGGO A) Lability of granular vesicles in market cells of SA I cutaneous receptors in the cat *Proc Int Union Physiol Sci* **14** 298
- Effect of opening the chest on the responses of aortic chemoreceptors *Proc Int Union Physiol Sci* **14** 298
- Introduction to Session III inputs *In Central Interaction Between Respiratory and Cardiovascular Control Systems* (Ed HP Koepkchen, SM Hilton, A Trzebski) 85-86 Berlin Springer-Verlag
- The relative location of low-and higher-threshold pulmonary stretch receptors *J Physiol* **307** 50-51
- 1981 Vagal sensory mechanisms and sensations *In Advances in Physiological Sciences* **16** (Eds E Grastyan & P Molnar) 309-313 Budapest Academiai Kiado
- Concluding remarks on visceral mechanisms and sensations *In Advances in Physiological Sciences* **16** (Ed E Grastyan and P Molnar) 335-337 Budapest Academiai Kiado
- (With CHUNG SS, LAKIE M and WALSH EG) Stretch reflexes in anaesthetized cats *J Physiol* **313** 44-45
- (With WALSH EG) Inhibition of tonic stretch reflex by J receptor activity *J Physiol* **316** 22-23
- 1982 (With ANAND A, LOESCHCKE HH and MAREK W) Significance of the respiratory drive by impulses form J receptors *J Physiol* **325** 14
- (With ANAND A and IGGO A) Genesis of the 'burst' discharge in primate cutaneous cold receptors *J Physiol* **327** 66-67



- 1983 Reflex effects of J receptors in *Central Neurone Environment* (Eds ME Schlafke, HP Koepchen and WR See) 134-141p Berlin Springer-Verlag
- (With ANAND A *et al*) Interpretation of the effect of carbon dioxide on aortic chemoreceptors *Proceedings of the international Union of Physiological Sciences XV* 140
- Localization of the sensations produced by J receptors (J Area) *Proc International Union of Physiological Sciences XV* 245
- (With RAVI K and ISLAM M) Estimate of reflexly effective activity in J receptors of dogs *Proc International Union of Physiological Sciences XV* 245
- (With REX MAE) Stimulation of laryngeal constrictor muscles by J receptors and cardiac receptors *Proc International Union of Physiological Sciences XV* 245
- The central effects of J receptors *Proc International Union of Physiological Sciences XV* 290
- Lung and Airways Receptors *Control of Respiration* (Ed DJ Pallot) 78-107 Croom Helm London and Canberra
- 1984 (With ANAND A) The detection of sub-threshold activity of J and other receptors in *Mechanoreceptors thermo-receptors and Nociceptors* (Eds W Hamman and A Iggo) 207-218 Singapore World Scientific Publishing Co Pvt Ltd
- 1985 High Altitude Studies Mountain Preservation and prosperity *Curr Sci* **54** 119-122
- (With ANAND A, DEV NB and RAVI K) Reflex effects elicited after injecting a local anaesthetic into the pericardial sacs of cats and dogs *J Physiol* **358** 125
- 1986 (With ANAND A and WHITTERIDGE D) Phosgene stimulates J receptors and produces increased respiratory drive in cats *J Physiol* **371** 109
- Visceral Sensations – some basic mechanisms *Progress in Brain Research* **67** 3-9
- The significance of dry cough breathlessness and muscle weakness *Indian Journal of Tuberculosis* **33** 51-55
- (With RAJ H and SINGH VK) Sensations produced by J receptors *Proceedings of the International Union of Physiological Sciences* **16** 308
- Pocity vyvolane drazenim Receptory Sensation form J- *Bratisl x Lek Listy* **33** 51-55
- 1988 (With ANAND A) The influence of the sympathetic outflow on aortic chemoreceptors of the cat during hypoxia and hypercapnia *J Physiol* (London) **39** 215-231
- The responses of chemoreceptors with medullated and non-medullated fibres to chemical substances and the mechanical hypothesis *Progress in Brain Research* **74** 337-340
- (With ANAND A) Possible role of capillary permeability in the excitation of sensory receptors by chemical substances *Progress in Brain research* **74** 337-340
- 1989 (With ANAND A, RAJ H ANAND and SINGH VK) A method for estimating changes in pulmonary capillary permeability in animals and man from the responses of J receptors to drugs *Journal of Physiology* **412** 36p
- (With ANAND A) Oxygen sensing by arterial chemoreceptors In *Response and adaptation to hypoxia organ to organelle* (Eds S Lahiri, NS Cherniack and RS Fitzgeralds) 81-94 Oxford University Press New York
- 1990 (With ANAND A) How real is the relation of arterial PO₂ to chemoreceptor activity? In *Arterial Chemoreceptors* (Eds C Eyzaguirre, SJ Fidone, RS Fitzgerald, S Lahiri & DM McDonald) 260-269 Springer-Verlag New York



- 1991 (With ANAND A) Estimating in vivo the blood concentration of chemical substances injected intravenously in anaesthetized cats use in studies on sensory receptors *Journal of Physiology* 438 247
- 1992 (With ANAND A) Factors affecting movement of excitatory substances from pulmonary capillaries to J receptors of anaesthetized cats *Journal of Physiology* 449 155-168
- 1993 The importance of J receptors in health & disease 11th Iranian Congress of Physiology & Pharmacology pp L-4
- (With ANAND A and WHITTERIDGE D) Mechanisms underlying enhanced responses of J receptors of cats to excitants in pulmonary oedema *Journal of Physiology* 471 553-547
- 1995 (With RAJ H, SINGH VK and ANAND A) Sensory origin of lobeline induced sensations A correlative study in man and cat *Journal of Physiology* 482 235-246
- Sensations form J receptors *News in Physiological Science* 10 238-243
- New knowledge about exertional breathlessness – Use & misuse *Proc Indian National Science Academy* B61 409-418
- Some recent advances in studies on J receptors In *Control of the Cardiovascular and Respiratory Systems in Health and Disease* (Eds MP Kaufman & CT Kappagoda) 14-26 Plenum Press New York
- 1997 *The Significance of Exertional Dyspnoea Ann Natl Acad Med Sci (India)* 32(1) 03-14
- 1998 Influence of J receptors on ventilation and maximum heart rate during rapid locomotion In *Respiratory Control Mechanisms and Sensations* 219-229 (Eds AS Paintal and A Anand) Vallabhbbhai Patel Chest Institute Delhi
- 1999 (With GANDEVIA SC, BUTLER JE, TAYLOR JL and ANAND A) No laughing matter *Lancet* 354(9195) 2086
- (With ANAND A) Respiratory function and the autonomic nervous system In *Handbook of Clinical Neurology Vol 74(30) The Autonomic Nervous System Part I Normal Functions* ed Appenzeller O Elsevier Science BV Amsterdam
- 2000 (With ANAND A) Present status of the mechanical hypothesis for chemoreceptor stimulation In *Oxygen Sensing Molecule to Man* (Eds S Lahiri, NR Prabhakar & RE Forster) 411-418 Plenum Press New York
- 2001 (With BUTLER JE *et al*) Changes in respiratory sensations induced by lobeline after human bilateral lung transplantation *Journal of Physiology* 534 583-593
- 2002 (With RAJ H and ANAND A) Lobeline-induced cough -a reflex form J receptors *Proceedings of the 5th FAOPS Congress* 183
- 2004 (With DEGHANI GA, PARVIZI MR, SHARIF-KAZEMI MB, RAJ H and ANAND A) Presence of lobeline-like sensation in exercising patients with LVD *Respiration Physiology & Neurobiology* 143 9-20
- 2005 (With RAJ H, BAKSHI GS, TIWARI RR and ANAND A) How does lobeline injected intravenously produce a cough? *Respiration Physiology & Neurobiology* 145 79-90
- (With ANAND A, JAIN PK, CHAWLA A and RAJ H) Origin of respiratory sensations and hyperventilation generated by releasing lower body negative pressure *Proc XXXVth IUPS Congress San Diego*

