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Preface

# "$Ca^{2+}$ signaling and cell death": The ECS 2013 workshop in Leuven and a tribute to Humbert De Smedt

In recent years it has become increasingly clear that changes in intracellular $Ca^{2+}$ homeostasis and dynamics are intimately associated with cell death and survival processes, including proliferation, apoptosis, autophagy, and unfolded protein response. As such, different $Ca^{2+}$ transport systems, including channels, transporters and pumps, control these processes. Furthermore, dysregulation of intracellular $Ca^{2+}$-signaling events and remodeling of $Ca^{2+}$-transport systems and their regulation by associated proteins and other cellular factors seem to be a hall-mark of several diseases, including different cancer types and neurodegenerative diseases. Understanding the molecular mechanisms underlying these events may now permit novel and unprecedented therapeutic strategies to target these $Ca^{2+}$-transport systems and complexes.

In this workshop, attended by more than 100 scientists from 20 different countries, four scientific sessions were organized, dealing with various aspects of $Ca^{2+}$-signaling in cell survival and cell death. The role of mitochondria, autophagy, ER stress and other factors and their influence on diseases have been discussed. Three contributions were awarded with the best oral communication and best poster prizes by junior scientists. The scientific career, achievements and mentorship of Humbert De Smedt were celebrated at the end of this workshop.

We summarize the lectures of this workshop, for details see the contributions of this special issue and the references listed therein.

## 1. Opening lecture by Katsuhiko Mikoshiba

The meeting was opened by an impressive keynote lecture given by Katsuhiko Mikoshiba (RIKEN, Japan), who 25 years ago identified the P400 protein as the $IP_3$-binding protein which turned out to be an $IP_3$-sensitive $Ca^{2+}$-release channel. He described in detail the critical roles of the different $IP_3R$ isoforms in development, cell function and diseases. Of special interest was his description of the critical roles of $IP_3R$ isoforms in cell death, since $IP_3R1$ channels are dysfunctional during prolonged ER stress-induced cell death. This has been attributed to an impaired interaction between the $IP_3R1$ channel and GRP78, an intraluminal chaperone and key regulator of the unfolded protein response. Very intriguingly, Dr. Mikoshiba discussed his view of $IP_3R$ as a hub for the interaction with a number of different regulators, especially IRBIT, which coordinates a plethora of ion channels and transporters [1].

## 2. Session 1: the complex role of $Ca^{2+}$ signaling in life and death

Dr. Prevarskaya (Lille, France) discussed the regulation of cell death by $Ca^{2+}$ signaling mechanisms in cancer cells, in particular by $Ca^{2+}$-influx channels. Dr. Prevarskaya described that next to the CRAC channels such as Orai1 different members of the transient receptor potential (TRP) family critically control cell proliferation and apoptosis. Cancer cells can switch their TRP-expression profile to promote oncogenic survival of malignant cells. Her research implicated a critical role for Orai channels in triggering $Ca^{2+}$ influx and subsequent apoptosis. Her group provided evidence that loss of Orai1 expression is one of the key factors that may underlie the appearance of aggressive and apoptosis resistant prostate cancers upon androgen ablation therapy. On the other hand, Prevarskaya and her group discovered that Orai3 is overexpressed in a set of prostate cancer cells obtained from patients, thereby promoting the proliferation of cancer cells. Finally, Orai1 and Stim1 seem to contribute to the apoptotic resistance of pancreatic adenocarcinoma [2].

Beyond plasmalemmal TRP and Orai channels, it also became evident from the presentation of Dr. Leybaert (Ghent, Belgium) that connexin channels, a conserved family of trans-membrane proteins of which more than 20 isoforms exist in mammals, critically control cell death spreading via gap junction- and hemichannel-dependent functions. Thus, intercellular $Ca^{2+}$ waves are propagated by the passage of $IP_3$ through those gap junctions triggering $Ca^{2+}$ release from reticular stores in the recipient cells. The spreading of $IP_3$ is critical but not sufficient for cell death. Hence, additional co-factors are required but still have to be identified. In any case, intercellular $Ca^{2+}$ waves are important for cell death and survival processes in a variety of physiological systems, including the brain, and pathophysiological conditions [3].

## 3. Session 2: $Ca^{2+}$, mitochondria and cell death

In a fascinating lecture Dr. Scorrano (Padova, Italy) described the proteins and mechanisms contributing to tethering complexes between the ER and mitochondria and their impact on cell life and death. Of special interest was his finding that mitofusin 2 (Mfn2), a dynamin-related GTPase, is enriched at ER–mitochondrial contact sites co-localizing with Bax in so-called *foci*. Mfn2-expression levels impact mitochondrial $Ca^{2+}$ transfer and apoptosis. Ablation of Mfn2 in mice is embryonic lethal, and Mfn2 mutations in human cause a sensorimotor neuropathy. Mfn2 is also critical for cardiac development and cardiomyocyte differentiation by orchestrating Notch signaling via $Ca^{2+}$ influx and calcineurin activation [4]. In his review, Dr. Scorrano discusses the emerging molecular links and functions of ER–mitochondrial tethers in and beyond $Ca^{2+}$ signaling, thereby controlling cell death and survival [5].

In her lecture Dr. Shoshan-Barmatz (Beer-Sheva, Israel), highlighted the functions of the voltage-dependent anion channel (VDAC) located

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in the outer mitochondrial membrane. In mammals, three homologous isoforms of similar molecular weights exist, namely VDAC1, 2 and 3. VDAC1 plays a crucial role in regulating metabolic and energetic functions of mitochondria as a high conductance channel for the flux of ATP. VDAC1 also participates in cell survival and death signaling from the mitochondria, e.g. by mediating the release of apoptogenic proteins such as cytochrome C. This is critically dependent on the ability of VDAC1 to form oligomeric structures, which occur in response to a plethora of apoptotic triggers [6].

An interesting view on the role of mitochondria for either cell survival or cell death was offered by Dr. Bernardi (Padova, Italy), who suggested that the old observation of mitochondrial permeability transition leading to matrix swelling of mitochondria may not be an *in vitro* artifact. In his opinion, the observation of the mitochondrial permeability transition leading to an increased permeability of the inner mitochondrial membrane to ions and solutes with molecular weights up to about 1.5 kDa is reflected by opening of a channel, the permeability transition pore (PTP), whose molecular nature remained elusive for a long time [7]. He provided evidence that the PTP is formed by dimerization of the $F_0F_1$ ATP synthase, since cyclophilin D, a regulator of PTP, binds to the oligomycin sensitivity-conferring protein subunit of the ATP synthase and Bz 423, an inhibitor of the synthase, influences the sensitivity of PTP to $Ca^{2+}$ [8]. Furthermore, purified dimers of the ATP synthase reconstituted into phospholipid bilayers reflect the electrophysiological properties of PTP. These PTP-like channel events could also be triggered by Bz 423 in the presence of $Ca^{2+}$. Hence, Dr. Bernardi concluded that the ATP synthase is not only the key enzyme of life, but also promotes signals to cell death.

## 4. Session 3: $Ca^{2+}$ and ER stress

Adaptation to and coping with stress are advantages of cells to struggle for survival. Dr. Michalak (Edmonton, Canada) reviewed in detail how cells can cope with ER stress. The ER is responsible for a wide variety of essential cellular housekeeping functions, among them the synthesis, folding, posttranslational modification, quality control and transport of proteins, and the uptake, storage and release of intracellular $Ca^{2+}$ to keep the cellular calcium homeostasis and dynamics in balance. Hence, disturbed ER functions and concomitant ER stress lead to the coordinated activation of the unfolded protein response (UPR), to correct and cope with the ER stress or to eliminate cells with irreparable ER stress. Three signaling proteins are important for UPR: i) IRE1α, an inositol-requiring endonuclease responsible not only for the unconventional splicing of XBP-1, but also for the degradation of RNAs including microRNAs, ii) PERK, a protein kinase RNA-like ER kinase that phosphorylates eukaryotic translation initiation factor 2α (eIF2α); and iii) ATF6, a transcription factor that translocates to the Golgi and is activated by proteolytic cleavage. Under normal conditions IRE1α, PERK and ATF6 are inactive due to their interaction with the ER chaperone BiP. Upon activation of UPR, BiP is released from IRE1α, PERK and ATF6, coordinating the expression of ER chaperones and anti-oxidants, ER-associated protein degradation, autophagy and apoptosis. Thus, the orchestrated action of IRE1α, PERK and ATF6 permits the cell to cope with ER stress and is an integral part of normal physiology, either to ensure cell survival or to eliminate damaged cells. This system is fundamental for the health of virtually all cells and tissues, including components of the cardiovascular system. The role and status of the UPR are also emerging being important for the survival of cancer cells [9].

Dr. Kaufman (La Jolla, USA), one of the pioneers of UPR research and its impact on human disease, related $Ca^{2+}$ signaling to protein folding through mitochondrial function. PERK-mediated phosphorylation of eIF2α on the one hand leads to the translation of ATF4 mRNA and on the other hand leads to a block in translation and general protein synthesis. Under mild or short-term ER stress, ATF4 promotes survival by upregulating a subset of adaptive UPR executioners, including foldases, oxidoreductases and proteins critical for autophagy induction. However, during prolonged or excessive ER stress, ATF4 also induces the transcription of CHOP, a long-known component of the pro-apoptotic UPR arm. Dr. Kaufman showed that the building of the ATF4/CHOP complex as a heterodimer is required to induce their target genes and promote UPR. On the other hand, in response to increased protein misfolding in the ER $Ca^{2+}$ leaks from the ER, thereby causing mitochondrial damage and increasing the probability of cell death [10].

## 5. Session 4: $Ca^{2+}$, endoplasmic reticulum and cell death

According to Dr. Foskett (Philadelphia, USA), anti-apoptotic proteins such as Bcl-2 or Bcl-XL regulate the release channel activity of $IP_3$ receptors by directly interacting with the C-terminal tail of $IP_3R$ to sensitize single channels in the ER to low $IP_3$ concentrations. Using patch clamp experiments with isolated nuclei from Sf9 cells expressing only $IP_3R1$, it was convincingly shown that Bcl-XL in the absence of $IP_3$ could not induce channel opening, but prominently sensitized $IP_3R$ channel activity in response to physiological concentrations of $IP_3$. This mechanism leads to pro-survival $Ca^{2+}$ oscillations that enhance mitochondrial bio-energetics and enable cells to resist apoptosis. Furthermore, this pathway seems an integral part of the anti-apoptotic effect of Bcl-XL in cells, since Bcl-XL overexpression was less effective in protecting against apoptosis in cells lacking $IP_3Rs$ versus cells expressing either one of the $IP_3R$ isoforms. Very recently, it was found that the $IP_3R$/Bcl-XL nexus is targeted and counteracted by PKC-phosphorylated K-ras, resulting in deficient ER–mitochondrial $Ca^{2+}$ transfer [11]. This is needed for efficient respiration, excessive autophagy activation and subsequent cell death. At the level of the mitochondria, it becomes increasingly clear that the recently identified mitochondrial $Ca^{2+}$ uniporter (MCU) is involved in mediating $Ca^{2+}$ uptake to stimulate ATP production and thus suppressing basal autophagy. The essential role of MCU in these processes is further supported by the finding that ablating mitochondrial calcium uniporter regulator 1 (MICUR1), an essential regulator of MCU-driven mitochondrial $Ca^{2+}$ uptake, abrogates oxidative phosphorylation, impairs the production of ATP and triggers AMP kinase-dependent autophagy as a pro-survival rescue mechanism [12].

Dr. Distelhorst (Cleveland, USA) explained the role of anti-apoptotic Bcl-2 proteins executing their role as cellular inhibitors of the $Ca^{2+}$-flux properties of $IP_3R$ channels. This interaction can be targeted using peptide tools that mimic the Bcl-2-binding site of $IP_3Rs$. Dr. Distelhorst described that in T cells Bcl-2 was essential to recruit DARPP-32 and calcineurin, the $Ca^{2+}$/calmodulin-dependent phosphatase PP2B, to $IP_3R$. This complex serves as a critical regulator of $IP_3R$-dependent $Ca^{2+}$ release important for the survival of cells, including primary chronic lymphocytic leukemia cells and is proposed as a new target in anticancer strategies [13].

**Fig. 1.** A picture of Humbert De Smedt, taken at the PhD defense of his last PhD student (13/12/2012).

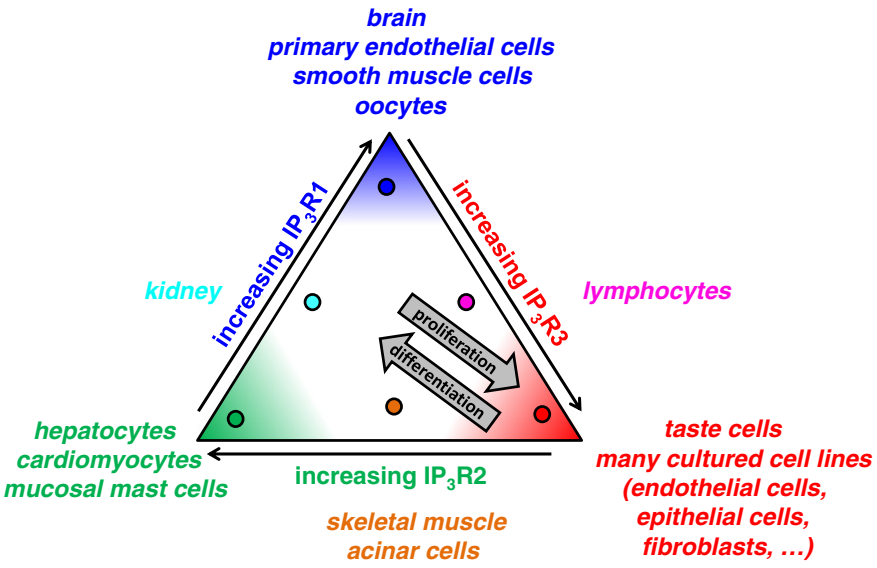


**Fig. 2.** A triangle presentation of the relative expression levels of the three different $IP_3R$ isoforms. The blue corner represents high $IP_3R1$ levels, the green corner represents high $IP_3R2$ levels, and the red corner represents high $IP_3R3$ levels. Different tissues and cell types display different $IP_3R$-isoform-expression profiles, which seem to be dynamically regulated during cell proliferation and differentiation. The figure is inspired by the original figure made by Humbert De Smedt and presented in its original form in this issue [16].

Finally, Dr. Hajnoczky (Philadelphia, USA) reported his results concerning one of the hot topics of the workshop, namely the junctions formed by mitochondria with the endoplasmic reticulum. He described these junctions as "quasi synaptic $Ca^{2+}$ signaling between ER and mitochondria", which can be biochemically isolated as mitochondrial–associated ER membranes. These junctions play a pivotal role in mediating calcium signal propagation to mitochondria, important for ATP production, a life signal, and mitochondrial cell death. Elegant tools have been developed by his group to chemically establish ER–mitochondrial contact sites, to visualize ER–mitochondrial contact sites and to measure $Ca^{2+}$ in the microdomain of the ER–mitochondrial contact sites [14]. Many of the ER–mitochondria $Ca^{2+}$ signaling events are sensitive to redox changes, probably exposed to reactive oxygen species (ROS) produced by mitochondria and/or the ER. Using a FRET-based strategy, Dr. Hajnoczky and his co-workers were able to measure local $Ca^{2+}$–ROS interactions at the ER–mitochondria interface and provided evidence for its relevance of the function of the mitochondria in both, cell survival and cell death. Recent work led to the determination of MICU1, as a critical regulator of MCU [15]. MICU1 critically determines the threshold and cooperativity of MCU-mediated $Ca^{2+}$ transport in the mitochondria. Ablating MICU1 enhances the uptake of low-level $Ca^{2+}$ signals, but dampens the uptake of larger $Ca^{2+}$ signals that were triggered by agonists.

## 6. Lecture and celebration of Humbert De Smedt

The scientific program was ended by Dr. De Smedt, who was a mentor and inspirer for many of us at the KU Leuven (Fig. 1). He inspired Jan B. Parys, Ludwig Missiaen and Geert Bultynck and numerous PhD students and post-doctoral researchers by his work on $IP_3R$ channels. He summarized twenty years of research in a 40 minute lecture. His work has led to key discoveries about the regulation of $IP_3Rs$ by intracellular $Ca^{2+}$ and redox systems. Furthermore, one of the key concepts put forward by Dr. De Smedt was that $IP_3R$ channels act as multi-protein complexes and are tightly regulated by a variety of proteins.

One of the key observations made by Dr. De Smedt long time ago concerned the isoform-expression profile of $IP_3Rs$ in different cell types and tissues (Fig. 2). In addition, cell lines in culture seem to be able to switch their $IP_3R$ isoform-expression profile depending on the conditions. Fig. 2 presents a schematic version explaining these ideas and visualizing the expression levels of the three $IP_3R$ isoforms in various tissues and cell types. This concept supports the finding that distinct $IP_3R$ isoforms play very diverse roles in cell-fate decisions [16].

## 7. Three awarded contributions by junior scientists

The best short oral communication, donated by the journal BBA-Molecular Cell Research, was given to Nicola Darling (Cambridge, UK) for her work entitled: "ERK1/2 signaling protects against ER stress-induced apoptosis" [17].

One poster prize, donated by the Biochemical Journal, was given to Alex van Vliet (Leuven, Belgium) for his poster entitled: "PERK is a component of the mitochondria-associated membranes that shape ER–mitochondria interactions during ER stress" [18].

Another poster prize, donated by Abcam®, was given to Dr. Haidar Akl (Leuven, Belgium) for his poster entitled: "Transforming the constitutively active $IP_3$ signaling in DLBCL and CLL into deadly $Ca^{2+}$ signals by targeting $IP_3R$/Bcl-2 complexes" [19].

## 8. Guest Editors

Geert Bultynck, Claus Heizmann, and Joachim Krebs served as Guest Editors of the ECS 2013 workshop in Leuven "$Ca^{2+}$ signaling and cell death."

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**Dr. Geert Bultynck** is a professor at the KU Leuven (Belgium). He received his Master degree in Biochemistry in 1997 and his PhD degree in Medical Sciences from the KU Leuven in 2001, studying the role of immunophilins in $Ca^{2+}$ signaling. In 2003-2006, he performed post-doctoral research in the laboratory of Prof. Martha Cyert (Stanford Univeristy, CA) on the discovery and characterization of novel calcineurin substrates in yeast. In 2008, he was appointed as an assistant professor in the Laboratory of Molecular and Cellular Signaling (KU Leuven, Belgium), joining the team of Prof. Humbert De Smedt, Prof. Jan B. Parys and Prof. Ludwig Missiaen. His main interest is to explore and exploit intracellular $Ca^{2+}$ signaling in health and disease with a strong focus on the role of anti-apoptotic Bcl-2-family members and pro-autophagy proteins like Beclin 1 in $Ca^{2+}$ signaling by directly targeting and controlling $Ca^{2+}$-transport systems. Recently, he edited together with Jan B. Parys, Martin Bootman and David Yule the book: "Calcium Techniques: A Laboratory Manual" (Cold Spring Harbor Laboratory Press, ©2014). He received different awards for his work, including in 2013 the prestigious Galenus Award for Pharmacology.

**Dr. Claus W. Heizmann** is Professor of Clinical Biochemistry at the University of Zurich in Switzerland. He received his Diploma in Chemistry from the University of Basel and his PhD in 1970 from the University of Konstanz, Germany. Subsequently he was trained as a post-doctoral fellow in the laboratory of Dr. Edmond Fischer at the University of Washington, Seattle and at the Federal Institute of Technology (ETH) in Zurich. In 1989–2007 he was Director of Clinical Chemistry and Biochemistry at the Department of Pediatrics at the University of Zurich. His research focuses on the structure and functions of calcium-binding proteins and RAGE in health and disease. Recently, he edited the book: Calcium-Binding Proteins and RAGE: from structural basics to clinical applications published in: Methods in Molecular Biology, Vol 963, Springer Protocols/Humana Press, 2013.

**Dr. Joachim Krebs** has been working in the field of calcium-binding and calcium-transporting proteins for many years. After receiving his PhD from the University of Tübingen, Germany, he spent 2 years as a postdoctoral fellow in the Lab of Prof. R.J.P.Williams at the Institute of Inorganic Chemistry at the University of Oxford, UK. In 1977 he accepted a position at the Institute of Biochemistry at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. He has authored, coauthored, and edited numerous articles in international journals and books in the field of calcium biochemistry and calcium signaling. After his retirement from the ETH he continued his research at the Department of NMR based Structural Biology of the Max Planck Institute for Biophysical Chemistry in Göttingen, Germany. Recently, he edited together with Marek Michalak from the University of Alberta, Edmonton, Canada, the book "Calcium: A Matter of Life or Death", published by Elsevier in 2007. He is also on the Editorial Board of BBA Molecular Cell Research and a Section Editor of Archives of Biochemistry and Biophysics.

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