FINAL REPORT

Physiological and pathophysiological role of transient receptor potential ion channels in the dental pulp

(NKFI-134725)

Background and aims

Thermosensitive members of the transient receptor potential (TRP) family of ion channels are key molecules in the somatosensory transduction. Expressed in the sensory neurons, they sense changes in external temperature, and contribute to nociception and itch detection, as well. Importantly, their function and expression can be upregulated in inflammatory conditions resulting in various forms of inflammatory hyperalgesia or allodynia. However, their expression is not restricted to sensory neurons, their presence was described in several non-neural cell types around the sensory nerve endings, e.g. in keratinocytes of the skin epidermis or various immune cells. Their activation on nonneural cells can also shape sensory transduction and can trigger the release of various mediators, among others inflammatory mediators. Therefore, TRP channels can shape the interaction between peripheral, non-neuronal cells and sensory neurons on both sides.

Recently the presence of TRP channels was described in the dental pulp in the innervating sensory fibers, as well as in the resident pulp cells, like odontoblast. However, their role in pulpal sensitivity and inflammatory processes is not elucidated. The most common cause of the pulpal inflammation (pulpitis) is bacterial infection reaching the pulp via carries. The different pathogenic components of the invaders will be recognized by Pattern Recognition Receptors of the resident pulpal cells, among which Toll-like receptors (TLRs) emerge. The activation of these receptors initiates inflammatory responses involving the release of inflammatory cytokines, proteolytic enzymes (e.g. matrix metalopeptidases) and reactive oxygen species. These inflammatory mediators may target TRP channels further contributing to the inflammatory reactions. Importantly, pulpal inflammation is often associated with characteristic dental pain and thermal or mechanical hyperalgesia and allodynia, in which TRP channels expressed in sensory nerve endings play a crucial role. Moreover, TRP channels of the non-neuronal cells may also contribute to the pathogenesis affecting e.g. the release of inflammatory mediators. Therefore, we aimed at investigating the role of sensory TRP channels in the dental pulp and study their contribution to inflammatory events in the pulp.

Results of the project

Pathogen- and damage-associated molecular patterns (PAMPs and DAMPs) induce inflammatory responses in human dental pulp cell (hDPC) cultures – leading role of TLR3

To increase the translational value of our study, we focused on human pulp and isolated primary cells (human dental pulp cells – hDPCs) from healthy human molar teeth removed for orthodontic reasons, as a clinically highly relevant model. We modelled the inflammatory conditions by stimulating TLRs of hDPCs applying various PAMPs and DAMPs. We used bacterial lipopolysaccharide (LPS, characteristic for gram-negative bacterial cell wall) as a ligand of TLR4, lipoteichoic acid (LTA, a characteristic marker of gram-positive bacteria), peptidoglycan (PGN) as ligands of TLR2, and polyinosinic:polycytidylic acid (PIC, an analouge of double strain RNA) as a ligand of TLR3. We carried out transcriptomic analysis (RNSseq) and additional qPCR, cytokine arrays, and ELISA experiments to characterize the effect of the different ligands in details. Interestingly, we found that the TLR3 ligand PIC was the most effective to induce inflammatory responses in the hDPC cultures. LPS

also induced the production of some inflammatory cytokines, while the TLR2 ligands LTA and PGN were found hardly effective.

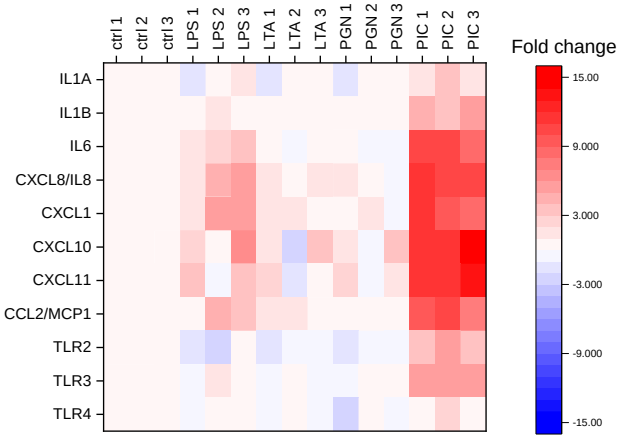

Figure 1. *Expression and upregulation of selected pro-inflammatory cytokines and Toll-like receptors in hDPC cultures of three donors (numbered consequently 1-3) in various conditions. Cells were treated with TLR-activating ligands for 24 hrs, then subjected to total RNA isolation and transcriptomic analysis by RNAseq.*

These results are in line with our findings, that expression level of TLR3 in hDPC cultures is higher than the level of TLR4, and TLR2 was found to be expressed at even lower level. These data supported the conclusion that hDPC cultures are especially vulnerable to advanced inflammation characterized by release of own RNA from the damaged, inflamed tissue. We are actually preparing a manuscript about the detailed characterization of the various inflammatory models **(11).** The poly(I:C)-induced inflammatory model was also used in our published MS **(2)**

Thermosensitive TRP channels are expressed in hDPCs

We have studied the molecular expression of thermosensitive TRP channels in (hDPC) cultures and studied their functionality using intracellular Ca^{2+} measurement techniques. We detected the transcripts of both warm- and cold-sensitive channels at various levels. A marked expression of the warm-sensitive TRPV2, and TRPV4 channels was measured in samples of several donors, while the expression of TRPV1 transcripts was ca. one magnitude lower and TRPV3, TRPM2 and TRPM3 were detected at low level and only in some of the donors. Transcripts of the cold-sensitive TRPA1 and TRPC5 were expressed at high level, but TRPM8, which is the main cold sensor in the somatosensory fibers, was not detected in any samples. We investigated the functionality of the TRP channels using pharmacological agonists, and found that 2-APB (an agonist of warm sensitive TRPV1, 2, and 3), and GSK1016790A (a specific agonist of TRPV4) resulted in Ca^{2+} signals while capsaicin and pregnenolone sulfate (agonists of TRPV1 and TRPM3) were ineffective. Importantly, TRPA1 was also found functional, its agonists AITC and CA evoked marked Ca^{2+} transients which were inhibited by the TRPA1 antagonists HC030031 and A967079. The most important findings were published in our recent paper **(2).**

TRPA1 is upregulated in inflammatory conditions and contributes to the inflammation-induced oxidative cell damage in hDPC cultures.

We have investigated the effect of inflammatory conditions on the TRP channels in hDPC cultures using the above established poly(I:C) induced inflammatory model. We found that TRPA1 (but not other thermosensitive TRPs) was highly upregulated and TRPA1-mediated responses were also strongly potentiated in inflammatory conditions. Moreover, we found that TRPA1 upregulation resulted in increased sensitivity toward reactive oxygen species (ROS), as exogenous H_2O_2 evoked more pronounced Ca^{2+} signals mediated by TRPA1. Importantly, the inflammatory condition was not only

associated with higher sensitivity toward ROS but also induced oxidative stress, upregulated mitochondrial superoxide production and mitochondrial superoxide dismutase. This oxidative stress impaired the cellular viability, especially mitochondrial functions. Our results indicated that this oxidative damage was partially mediated by TRPA1. We found that both pharmacological inhibition and siRNA-mediate silencing of TRPA1 partially protected against inflammation-induced mitochondrial disfunctions. These results indicate that pulpal TRPA1 is a promising pharmacological target to combat pulpitis. **(2)**

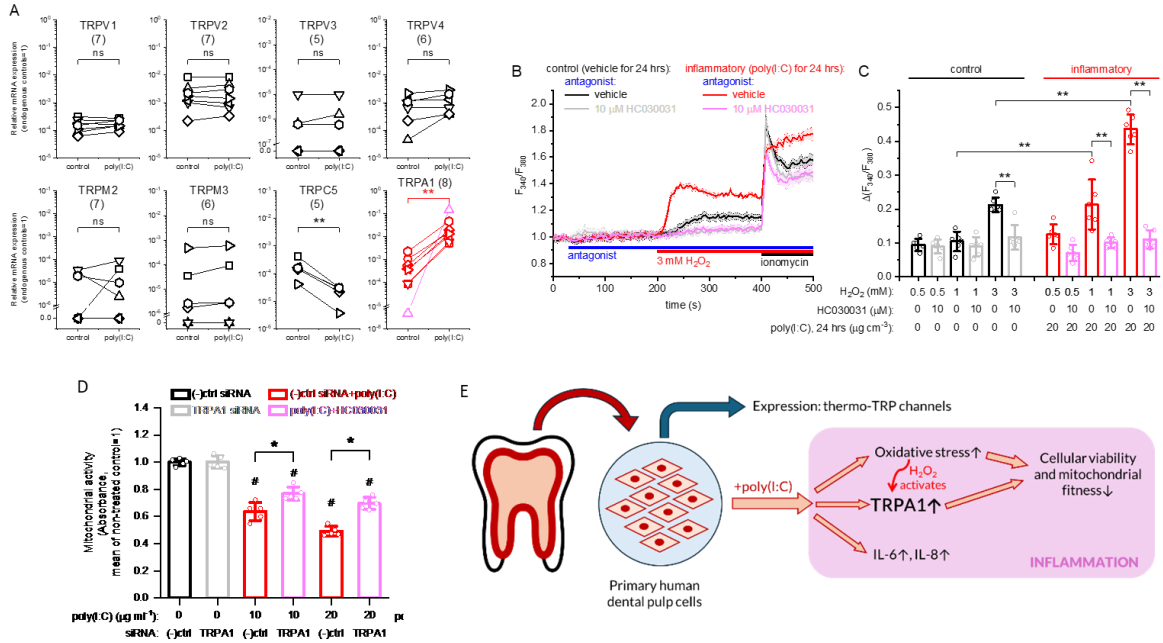

Figure 2. Upregulated TRPA1 mediates oxidative cellular damage of hDPCs in poly(I:C) induced inflammation. A. *Poly(I:C) upregulated TRPA1, but not other TRP channels. Number of donor investigated is indicated in parentheses.* ***B.*** *H_2O_2 induced changes in intracellular Ca^{2+} concentration in control and inflammatory conditions are mediated by TRPA1 (HC030031 – TRPA1 antagonist).* ***C.*** *Statistical analysis of the measurements shown in panel B. N=5.* ***D.*** *Silencing of TRPA1 expression partially protects against inflammation induced mitochondrial disfunctions. EZ4U assay, N=5.* ***E.*** *Graphical summary of the results. *p<0.05; **p<0.01; ***p<0.001. (Selected figures from Kunka et al, 2024.)*

Based on the above in vitro results demonstrating the importance of TRPA1 in inflammation induced oxidative damage, we assumed that TRPA1 may also contribute to the tooth bleaching induced pulpal damage. Earlier studies indicated that H_2O_2 used for tooth bleaching can harm the pulp. Therefore, we initiated a collaboration with Dr. Viktoria Kormos (Department of Pharmacology and Pharmacotherapy, University of Pécs Medical School) to investigate the role of TRPA1 in beaching induced pulpal damage in vivo using *Trpa1*$^{+/+}$ and *Trpa1*$^{-/-}$ mouse strains available in Dr. Kormos' lab. We wanted to use histological staining and RNAscope in situ hybridization to investigate the expression of TRPA1 and markers of pulpal damage following bleaching treatment of mouse incisor teeth. Therefore, we had to overcome the challenge of decalcification of the teeth while preserving the integrity of both pulpal structure and mRNA. To achieve these goals, we have tested several strategies (5 different decalcification methods combined with three different retrieval protocol) and set a reliable decalcification method. We found that although all 5 decalcification methods preserved the histological

structure of the pulp, only two (ACD decalcification buffer and Morse solution) resulted in high-quality RNA properly suitable for RNAscope in situ hybridization. Taking into account other parameters, we concluded that the best suitable method for decalcifying mouse teeth for RNAscope in situ hybridization is the Morse solution. As this information can be useful for the scientific community we are preparing a manuscript discussing the effectivity of the different methods **(10)**.

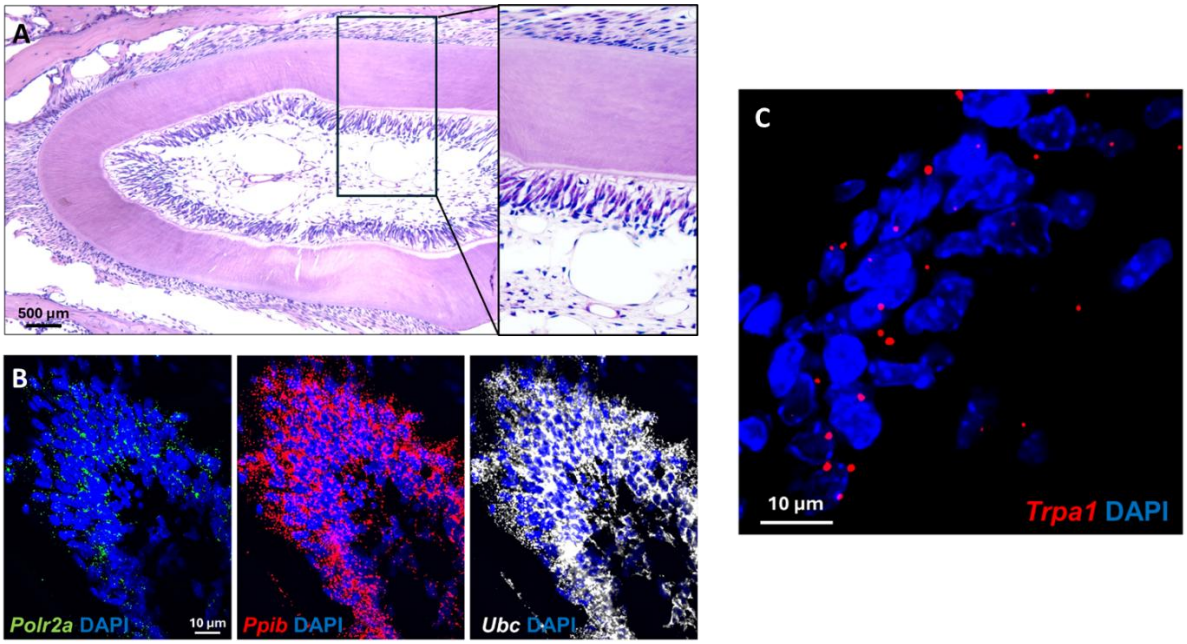

Figure 3. TRPA1 transcripts are detected in mouse incisor following an optimized decalcification using Morse solution A. *A representative image of a hematoxilin-eosin stained section indicating intact histological structure following decalcification with Morse solution.* ***B.*** *RNAscope stainings of endogenous control transcripts with low (Polr2a), intermediate (Ppib), and high (Ubc) copy number demonstrate preserved RNA integrity after decalcification with Morse solution.* ***C.*** *TRPA1 is detected in mouse dental pulp after decalcifying with Morse solution.*

We could also detect TRPA1 transcripts in mouse pulp in situ using this method. To investigate its role in H_2O_2 bleaching-caused pulpal damage, we treated incisors of *Trpa1*$^{+/+}$ and *Trpa1*$^{-/-}$ mice with bleaching gels containing a standardized concentration of H_2O_2 and we are subjecting the teeth to decalcification, histological analysis, and RNAscope to describe putative structural damage and inflammatory markers in the pulp. We are comparing the results from *Trpa1*$^{+/+}$ and *Trpa1*$^{-/-}$ mice to assess the potential role of TRPA1 in bleaching-induced pulpal damage. The histological analysis and the RNAscope experiments are ongoing. Based on these results, we will submit an additional manuscript for publication in 2025.

TRP channels and Piezo 1 mediate mechanosensitivity of odontoblast-like cells

The dental pulp contains several cell types among which odontoblasts form the outermost cellular layer lining the inner surface of dentin. Their most important function is the synthesis and maintenance of dentin, but they also possess important sensory functions. They are supposed to detect both thermal and mechanical stimuli via detecting hydrokinetic forces of fluid movement in the dentin tubules, however, their direct temperature sensitivity is also described. Highly specialized, differentiated primary odontoblast cannot be kept in proliferating cultures in vitro, therefore we adopted and set a generally used protocol to differentiate our hDPC cultures into odontoblast-like cells (OBLCs). These differentiated OBLCs (but not hDPCs) produced a highly mineralized extracellular matrix indicating

their odontoblast-like nature. As odontoblasts are in the frontline detecting external stimuli as well as pathogen invasion, we systematically investigated the mechanosensitivity and the function of the underlying ion channels in OBLCs differentiated from our primary hDPCs. To stimulate the OBLCs mechanically, we applied hypotonic solutions resulting in cellular swelling which stretches the membrane and activates mechanosensitive ion channels. We indeed found, that hypotonic solutions induced Ca^{2+} influx which was inhibited by GsMTx4 (a peptide toxin, general inhibitor of mechanosensitive ion channels) and was abolished in the absence of extracellular Ca^{2+} indicating the presence of functional mechanosensitive Ca^{2+} channels in the plasma membrane.

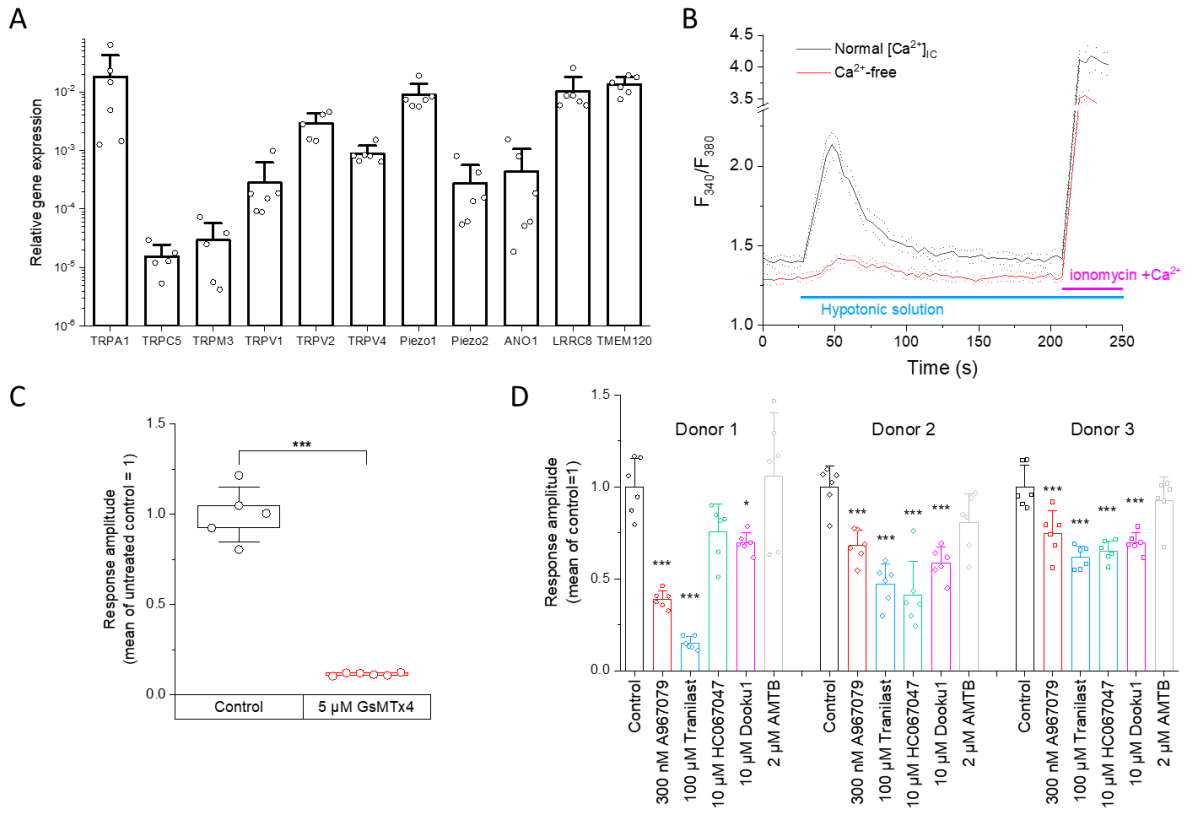

Figure 4. Mechanosensitive Ca^{2+} channels in OBLCs are activated by hypotonic stress. A. *Expression of mechanosensitive ion channel transcripts in OBLCs isolated from different donors, N=5-6.* ***B.*** *Hypotonic solution-induced intracellular Ca^{2+} traces in normal and Ca^{2+}-free solutions, averaged record, N=6.* ***C.*** *Amplitude of the hypotonic stress induced Ca^{2+} signals is dramatically decreased by GsMTx4, a general inhibitor of mechanosensitive channels, N=5-6, ***p<0.001 by indepentend sample t-test.* ***D.*** *Inhibitors of TRP and Piezo channels partly reduce the Ca^{2+} responses of OBLCs to mechanical (hypotonic) stimuli. Note the differences between cultures from different donors. N=6 in each group, *p<0.05; ***p<0.001, ANOVA, Dunnett post-hoc test. Applied inhibitors: A967079 – TRPA1, Tranilast – TRPV2, HC067047 – TRPV4, Dooku 1 – Piezo 1, AMTB – TRPM8.*

Using qPCR, we have detected marked expression of thermo- and mechanosensitive TRP channels TRPV1, TRPV2, TRPV4 and TRPA1. TRPM3 and TRPC5 were detected only in some of the donors at low level and TRPM8, similar to hDPCs, was not detected in OBLCs. Next to the TRP channels, Piezo 1 and Piezo 2 were also detected, among them Piezo 1 expression was found ca. 10-fold higher. (Next to calcium channels, we also demonstrated the expression of mechanosensitive Cl^- channels, ANO-1 and LLRC8, as well as TMEM120A/TACAN).

Using various agonist and antagonists, we could confirm the functionality of TRPV2, TRPV4, TRPA1, and Piezo 1 but not TRPV1, TRPM8. Hypotonicity induced Ca^{2+} influx was also partly inhibited by the antagonists of TRPV2, TRPV4, TRPA1, and Piezo 1 indicating that all these channels can contribute to the mechanical activation of the OBLCs. Comparing OBLC cultures of different donors, we found that the contribution of the individual channels displays a marked variability between donors. The manuscript presenting our results about the mechanosensitivity of the OBLCs **(12)** is under preparation and it is planned to submit in the following months.

Pharmacological targeting of TRP channels

In frame of a long-lasting collaboration with Prof. Thomas Voets, (Laboratory of Ion Channel Research, KU Leuven) we found that the immunosuppressant Rapamycin selectively inhibits TRPM8 via novel mechanisms, and we characterized the structure-function relationship in detail **(1)**. In a newly established collaboration with Dr. Éva Szőke, we investigated the effect of lipid raft distruptors on the activity of TRPM8 and TRPM3 **(3).** Finally, in our current study, we are investigating the anti-inflammatory role of 3-O-acetyl-11-keto-β-boswellic acid (AKBA) on hDPCs using the above described poly(I:C) and LPS-induced inflammatory models. Our results indicate that AKBA attenuates the production of inflammatory cytokines, supports cellular viability, and inhibits the upregulation of TRPA1. We are currently closing the experiments and plan to publis the results by September 2025 **(13)**. These results can pave the way for developing new pharmacons targeting thermosensitive nociceptor TRP channels highly expressed in the dental pulp and in the innervating trigeminal sensory fibers.

Additional results related to the project

We took part in several collaborative research projects that complementary supported our findings. In these studies, we partly utilized the technical expertise gained from the work with dental pulp cells and investigated general immune regulatory functions that may be relevant in inflammation control. We investigated the effect of anandamide, a TRPV1/CB1 agonist, in inflammatory conditions in human corneal epithelial cells. In this study, we used, among others, a TLR3 activation-based inflammatory model, related to the model established in hDPC cultures **(7)**. Moreover, we studied other aspects, how TRP channels and related cannabinoid signaling can influence immunological functions. In the frame of a collaboration with the Department of Immunology, we found that cannabidiol applied during the differentiation shifted the phenotype of monocyte-derived dendritic cells toward more tolerogenic and primed anti-inflammatory responses **(4).** Ca^{2+} signaling regulated by TRP channels is an important pathway to control inflammation in the pancreas, as well. Participating in an international collaboration, we dissected the role of the Ca^{2+}-regulated TRPM4 in linking intracellular Ca2+ signals to the control of membrane potential in pancreatic acinar cells **(9)**.

We also published three review articles about TRP channels and inflammatory signaling pathways. We summarized the role of TRPM3 in the central nervous system **(8)** and the importance of the intercellular interactions between resident tissue cells, immune cells, and sensory fibers to generate pruritus **(5)**. We also overviewed the role of opioidergic signaling in the regulation of atopic dermatitis and related inflammation **(6)**.

Execution of the original project plan

We mainly followed the original project plan with minor deviations. Due to the COVID19 pandemic we experienced some delay in the execution. However, most of the planned research tasks are completed by the closing date, but some results are still to be published in the following months.

Detailed list of disseminations related to the project

Published papers with the support of the project

1. Tóth BI*, Bazeli B*, Janssens A, Lisztes E, Racskó M, Kelemen B, Herczeg M, Nagy TM, E. Kövér K, Mitra A, Borics A, Bíró T, Voets T. (2024) Direct modulation of TRPM8 ion channels by rapamycin and analog macrolide immunosuppressants. ***eLife**, published as reviewed preprint, https://doi.org/10.7554/eLife.97341.1* IF:6.4 (IF 2023)

2. Kunka Á, Lisztes E, Bohács J, Racskó M, Kelemen B, Kovalecz G, D. Tóth E, Hegedűs Cs, Bágyi K, Marincsák R, Tóth BI. (2024) TRPA1 upregulation mediates oxidative stress in a pulpitis model in vitro. ***Br J Pharmacol**., 181(17):3246-3262. https://doi.org/10.1111/bph.16386.* IF:6.8 (IF 2023)

3. Horváth Á, Steib A, Nehr-Majoros A, Kántás B, Király Á, Racskó M, Tóth BI, Szánti-Pintér E, Kudová E, Skoda-Földes R, Helyes Zs, Szőke É. (2024) Anti-Nociceptive Effects of Sphingomyelinase and Methyl-Beta-Cyclodextrin in the Icilin-Induced Mouse Pain Model. ***IJMS – International Journal of Molecular Sciences**. 25(10), 4637, https://doi.org/10.3390/ijms25094637* IF: 4.9 (IF 2023)

4. Pénzes Z, Alimohammadi S, Horváth D, Oláh A, Tóth BI, Bácsi A, Szöllősi AG. (2023) The dual role of cannabidiol on monocyte-derived dendritic cell differentiation and maturation. ***Front Immunol.** 14(14), 1-15, https://doi.org/10.3389/fimmu.2023.1240800* IF:5.7 (2023)

5. Szöllősi AG, Oláh A, Lisztes E, Griger Z, Tóth BI. (2022) Pruritus: a sensory symptom generated in cutaneous immuno-neuronal crosstalk. ***Front Pharmacol.** 13, 745658. https://doi.org/10.3389/fphar.2022.745658* IF:5.6

6. Ádám D, Arany J, Tóth KF, Tóth BI, Szöllősi AG, Oláh A. (2022) Opioidergic Signaling-A Neglected, Yet Potentially Important Player in Atopic Dermatitis. ***Int J Mol Sci.** 23(8), 4140 https://doi.org/10.3390/ijms23084140* IF:5.6

7. Angyal Á, Pénzes Z, Alimohammadi S, Horváth D, Takács L, Vereb G, Zsebik B, Bíró T, Tóth KF, Lisztes E, Tóth BI, Oláh A, Szöllősi AG. (2021) Anandamide Concentration-Dependently Modulates Toll-Like Receptor 3 Agonism or UVB-Induced Inflammatory Response of Human Corneal Epithelial Cells. ***Int J Mol Sci.** 22(15), 7776, https://doi.org/10.3390/ijms22157776* IF:6.208

8. Held K, Tóth BI. (2021) TRPM3 in Brain (Patho)Physiology. ***Front Cell Dev Biol.** 9:1-16. https://doi.org/10.3389/fcell.2021.635659* IF:6.081

9. Diszházi G, Magyar ZÉ, Lisztes E, Tóth-Molnár E, Nánási PP, Vennekens R, Tóth BI, Almássy J. (2021) TRPM4 links calcium signaling to membrane potential in pancreatic acinar cells. ***J. Biol. Chem.** 297(3), 1-5, https://doi.org/10.1016/j.jbc.2021.101015* IF:5.486

Manuscripts in preparation

10. Attila Szentágotai, Árpád Kunka, Erika Lisztes, Rita Marincsák, Balázs István Tóth, Viktória Kormos: Optimization of decalcification and tissue preparation protocol for RNAscope in situ hybridization in rodent tooth (working title). ***Manuscript in preparation to be submitted to the Journal of Endodontics***. Planned submission by March 2025.

11. Bohács J, Racskó M, Lisztes E, Kunka Á, Oláh A, Szöllősi AG, Bágyi K, Marincsák R, Tóth BI: Differential immune responses of human dental pulp cells to pathogen-associated molecular patterns activating toll like receptors (working title). ***Manuscript in preparation to be submitted to the Journal of Dental Research***. Planned submission by May 2025.

12. Racskó M, Lisztes E, Bohács J, Kunka Á, Bágyi K, Marincsák R, Tóth BI: Odontoblast-like cells express multiple mechanosensitive Ca^{2+} channels. (working title). ***Manuscript in preparation to be submitted to***

the Biochemical Pharmacology. Planned submission by April 2025.

13. Bohács J, Racskó M, Lisztes E, Kunka Á, Bágyi K, Tóth BI, Marincsák R: 3-O-acetyl-11-keto-β-boswellic acid (AKBA) exerts anti-inflammatory effects in the human dental pulp. (working title). ***Manuscript is planned to be submitted to the International Endodontics Journal***. Planned submission by September 2025.

Presentations on national and international conferences

14. Racskó Márk, Kunka Árpád, Bohács Judit, Lisztes Erika, Marincsák Rita, Tóth István Balázs (2024) Sensory TRP channels in the human dental pulp and their role in pulpitis. HUPHAR2024 (Hungarian Society of Experimental and Clinical Pharmacology), Mátraháza, 5-7. 06. 2024 - oral
15. Balázs István Tóth, Bahar Bazeli, Annelies Janssens, Erika Lisztes, Márk Racskó, Balázs Kelemen, Mihály Herczeg, Milán Tamás Nagy, Katlin Kövér, Argha Mitra, Attila Borics, Tamás Bíró,, Thomas Voets (2024) Rapamycin and analogue macrolide immunosuppressants activate the cold sensor TRPM8 ion channel. 'INC 2024 – International Neuroscience Conference 2024, Pécs, 25-26. 06. 2024. - poster
16. Bohács Judit, Racskó Márk, Lisztes Erika, Kunka Árpád, Bágyi Kinga Ágnes, Kovalecz Gabriella, Tóth István Balázs, Marincsák Rita (2024) Mechanoszenzitív kalcium-csatornák vizsgálata odontoblasztszerű sejteken. MÉT (Magyar Élettani Társaság) Vándorgyűlés 2024, Debrecen, 29-31. 05. 2024. - oral
17. Bohács Judit, Kovalecz Gabriella, Racskó Márk, Lisztes Erika, Kunka Árpád, Bágyi Kinga, Marincsák Rita, Tóth István Balázs (2024) A boswellinsav gyulladáscsökkentő hatásának vizsgálata humán pulpális sejteken. MÉT (Magyar Élettani Társaság) Vándorgyűlés 2024, Debrecen, 29-31. 05. 2024. - poster
18. R. Marincsák, M. Racskó, J. Bohács, E. Lisztes, Á. Kunka, K.Á. Bágyi, G. Kovalecz, B.I. Tóth (2023) Investigation of odontoblast mechanosensitivity. 21th ESE (European Society of Endodontology) Biennial Congress, Helsinki, 06-09. 09. 2023. – oral
19. Márk Racskó, Árpád Kunka, Judit Bohács, Erika Lisztes, Gabriella Kovalecz, Etelka D. Tóth, Kinga Bágyi, Rita Marincsák, Balázs István Tóth (2023) Investigation of odontoblast mechanosensitivity. FAMÉ2023, Mátraháza, 07-10. 06. 2023. - poster
20. Árpád Kunka, Judit Bohács, Erika Lisztes, Márk Racskó, Kinga Bágyi, Gabriella Kovalecz, Balázs Kelemen, Rita Marincsák, Balázs István Tóth (2022) Thermosensitive Transient Receptor Potential (TRP) ion channels in human dental pulp cells in normal and inflammatory conditions. Europhysiology 2022, Copenhagen, 16-18. 09. 2022. - poster
21. Marincsák Rita, Kunka Árpád, Bohács Judit, Lisztes Erika, Racskó Márk, Bágyi Kinga, Kovalecz Gabriella, Kelemen Balázs, Tóth István Balázs (2022) Thermosensitive Transient Receptor Potential (TRP) ion channels in human dental pulp cells, 20th ESE (European Society of Endodontology) Biennial Congress, Budapest, 07-10. 09. 2022. - oral
22. Kunka Árpád, Bohács Judit, Lisztes Erika, Racskó Márk, Bágyi Kinga,Kovalecz Gabriella, Kelemen Balázs, Marincsák Rita, Tóth István Balázs (2022) Termoszenzitív TRP ioncsatornák szerepe a humán fogpulpa sejtjein. MÉT (Magyar Élettani Társaság) Vándorgyűlés 2022, Budapest, 13-16. 06. 2022. - oral
23. Kunka Árpád, Bohács Judit, Lisztes Erika, Bágyi Kinga, Kovalecz Gabriella, Molnár Dóra, Kelemen Balázs, Marincsák Rita, Tóth István Balázs (2021) Hőérzékeny Transient Receptor Potential (TRP) ioncsatornák szerepe a humán fogpulpában. 50. Membrán-transzport Konferencia, Sümeg, 16-19. 11. 2021. - Poster, poster prize, oral
24. Arpad Kunka, Judit Bohács, Erika Lisztes, Kinga Bágyi, Gabriella Kovalecz, Dóra Molnár, Balázs Kelemen, Rita Marincsák, Balázs István Tóth (2021) Investigation of thermosensitive Transient Receptor Potential (TRP) ion channels in the human dental pulp. TRP2021, Leuven, 15-18. 09. 2021. - poster