P₂Y₂ Receptors Mediate Masseter Muscle Mechanical Hypersensitivity in Rats

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**Purpose:** P₂Y₂ receptors (P₂Y₂Rs) are among the various receptors that play an important role in nociception. The goal of this research was to investigate possible P₂Y₂R expression changes in the trigeminal ganglion (TRG) in bilateral masseter muscle (MM) hypersensitivity following unilateral MM inflammation. The impact of unilateral intramuscular administration of P₂Y₂R antagonist on bilateral MM hypersensitivity was also explored.

**Materials and Methods:** Bilateral MM hypersensitivity was provoked by unilateral intramuscular injection of complete Freund’s adjuvant (CFA). The head withdrawal threshold (HWT) was assessed bilaterally 4 days later. Bilateral TRG and MM isolation were followed, and quantitative real-time polymerase chain reaction (qRT-PCR) and histopathological analysis were carried out on these tissues, respectively. The involvement of P₂Y₂Rs in nocifensive behavior was evaluated by administering two doses of P₂Y₂R antagonist AR-C118925 (0.2 or 1 mg/100 μL) in inflamed MM 4 days post-CFA administration. Bilateral HWT was assessed at different time points following antagonist injection.

**Results:** qRT-PCR analysis demonstrated P₂Y₂R up-regulation in TRG ipsilateral to the site of CFA administration. Compared to the controls, both doses of AR-C118925 injected ipsilateral to the TRG increased the bilateral HWT at 30, 60, 90, and 120 minutes after antagonist administration.

**Conclusion:** The findings suggest that P₂Y₂Rs may affect MM inflammatory hypersensitivity owing to its up-regulation in the TRG in MM inflammatory pain states.

**Keywords:** facial pain, masticatory muscles, temporomandibular disorders, trigeminal ganglion

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**Plain Language Summary**

The pathophysiology of masticatory muscle (MM) pain in temporomandibular disorders (TMDs) remains unclear. Many studies have established the importance of various receptors in the pathophysiology of pain conditions, and P₂Y₂ receptors (P₂Y₂Rs) are among them. The goal of this study was to establish whether P₂Y₂-Rs mediate pain transmission from MM in rats. This study involved a behavioral assessment in rats along with laboratory analysis of MM tissue and trigeminal ganglion (TRG) tissue. The TRG mediates pain transmission originating from the MM. Rats were unilaterally injected with complete Freund’s adjuvant (CFA), a reagent that develops inflammation in the MM. A behavioral assessment was performed 4 days later and found bilateral MM mechanical hypersensitivity. Histopathological evaluation confirmed the development of inflammation in CFA-injected MM, and qRT-PCR showed that P₂Y₂-Rs were up-regulated in the TRG ipsilateral to the CFA injection site. In addition, the effect of two different doses of AR-C118925 on bilateral mechanical hypersensitivity was evaluated. AR-C118925 is a selective antagonist of P₂Y₂Rs. CFA-injected rats received an injection of AR-C118925 into the same MM, and behavioral
assessment followed 15, 30, 60, 90, and 120 minutes after the antagonist injection. Both doses of AR-C118925 resulted in a significant reduction in bilateral mechanical hypersensitivity at 30, 60, 90, and 120 minutes after injection of the antagonist. These results suggest that \( \text{P}_2\text{Y}_3 \)Rs may affect MM inflammatory hypersensitivity because they are up-regulated in TRG in MM inflammatory pain conditions. Their blockage with an antagonist is likely to reduce mechanical hypersensitivity.

**Introduction**

Temporomandibular disorders (TMDs) are a set of masticatory muscle and/or temporomandibular joint conditions, and muscle pain is the primary complaint in TMD patients.\(^1,2\) TMD afflicts 5–12% of the population, primarily the working population between 20 and 40 years of age. This represents a severe public health issue due to the physical and functional limitations, psychosocial discomfort and reduced quality of life reported by these patients.\(^3,4\) Previous scientific studies in this area have focused on the relationship between multiple etiological factors and TMD onset. Recent studies have concentrated on the mechanism changes related to pain that are present in TMD, and they have highlighted the crucial role of ion channels and receptors within these pain mechanisms.\(^5-7\)

Neurons of the trigeminal ganglion (TRG) are a peripheral component of the orofacial pain transmission pathway. These neurons express various receptors such as purinergic receptors, \( \text{P}_2\text{R} \), transient receptor potential vanilloid 1, \( \text{TRPV}_1 \), gamma-aminobutyric acid, GABA(B), voltage-gated potassium channel KCNQ, acid sensing ion channel, ASIC. The importance of various receptors in pain transmission mechanisms has been confirmed in many recent studies that have suggested receptor up-regulation or down-regulation in pain conditions.\(^8-12\)

The \( \text{P}_2\text{Rs} \) include the \( \text{P}_2\text{Y} \) receptor (\( \text{P}_2\text{YR} \)) and \( \text{P}_2\text{X} \) receptor families (\( \text{P}_2\text{XR} \)), and both families are involved in pain transmission. The most important ligands for these receptors are uridine triphosphate (UTP) and/or adenosine triphosphate (ATP), which are delivered from intracellular sources during inflammation and in various types of tissue damage. ATP and UTP bind to \( \text{P}_2\text{XR} \)s and/or \( \text{P}_2\text{Y} \)Rs, leading to their activation and subsequent intracellular cascade reactions in different physiological and pathophysiological processes, including pain transmission.\(^13,14\) Functions of \( \text{P}_2\text{XR} \)s and \( \text{P}_2\text{Y} \)Rs have not been thoroughly investigated. The role of \( \text{P}_2\text{XR} \)s remains unclear, and there are even fewer studies concerning the role of \( \text{P}_2\text{Y} \)Rs. The \( \text{P}_2\text{YR} \) family includes eight G protein-coupled receptors that play crucial roles in intracellular pathways. Their actions involve G protein binding and subsequent ionic conductance and/or second messenger system activation, resulting in a longer response time compared to \( \text{P}_2\text{XR} \)s. The \( \text{P}_2\text{YR} \) family also plays an essential part in regulating the activity of membrane voltage-gated ion channels.\(^15-17\)

Many different cell types express \( \text{P}_2\text{Y} \) \( _2 \) receptors (\( \text{P}_2\text{Y}_2 \)Rs). According to a recent study, the constitutive \( \text{P}_2\text{Y}_2 \)Rs activity produces intracellular \( \text{Ca}^{2+} \) tone and suppresses basal lipolysis via an adenylylate cyclase-dependent mechanism in human adipocytes.\(^18\) Muoboghare et al have suggested that UTP acts via \( \text{P}_2\text{Y}_2 \)Rs to mobilise \( \text{Ca}^{2+} \) in human endothelial cells.\(^19\) Recent studies have investigated the role of \( \text{P}_2\text{Y}_2 \)Rs in pain mechanisms, but their exact function remains unclear, especially in the fields of orofacial pain and TMD. \( \text{P}_2\text{Y}_2 \)Rs (along with \( \text{P}_2\text{Y}_1 \) receptors) are the major \( \text{P}_2\text{Y} \)Rs expressed in small-diameter sensory neurons.\(^15\) \( \text{P}_2\text{Y}_2 \)R stimulation increases neuronal excitability through \( \text{Kv}7 \) voltage-gated potassium channel inhibition and \( \text{TRPV}_1 \) facilitation.\(^20\) Previous results suggest that \( \text{P}_2\text{Y}_2 \)R inhibition enhances potassium channel expression and subsequent analgesia development in trigeminal neuropathic pain and that \( \text{P}_2\text{Y}_2 \)R activation is related to inflammatory mechanical allodynia.\(^21,22\) There is also evidence that \( \text{P}_2\text{Y}_2 \)R take part in the hyperalgesia mechanism by sensitizing ASICs in primary sensory neurons.\(^23\) Furthermore, a recent study established the involvement of glial \( \text{P}_2\text{Y}_2 \)Rs in pain.\(^8\) Together, these findings suggest that \( \text{P}_2\text{Y}_2 \) receptors play a very important function in nociception mechanisms.

Several recent studies have reported the involvement of different receptors in inflammatory pain states in the orofacial region. Therefore, we hypothesized that the onset of bilateral masseter muscle (MM) hypersensitivity following unilateral MM inflammation involves, among other receptor changes, \( \text{P}_2\text{Y}_2 \)R expression enhancement in TRG neurons. We also surmised that unilateral administration of a \( \text{P}_2\text{Y}_2 \)R antagonist into the MM could attenuate the bilateral MM hypersensitivity. The aim of this study was to determine possible \( \text{P}_2\text{Y}_2 \)R changes in the TRG during bilateral hypersensitivity following unilateral MM inflammation. The impact of an intramuscular injection of \( \text{P}_2\text{Y}_2 \)R antagonist on bilateral nociceptive behavior was also investigated.

**Materials and Methods**

**Experimental Animals**

Experiments were conducted using 54 Wistar rats (\( n=54 \)). The animal characteristics, housing protocols, and treatment protocols are described in detail in our previous...
Briefly, adult male rats weighing 250–300g were housed in groups of two to three per cage under a 12h/12h light/dark cycle. The rats were housed in a controlled temperature (22±2°C) and humidity (55±10%) environment with food and water access ad libitum. All efforts were made to ensure the minimal number of animals used in the experiment and minimal animal suffering.

All experimental protocols were approved and conducted in accordance with the institutional Ethics Committee, the Croatian national laws and rules (Official Gazette 135/06, 37/13, and 55/13), the European Community Council Directive (86/609/EEC), the Cabinet for Veterinary and Food Safety within the Croatian Ministry of Agriculture, and the Faculty of Medicine Ethics Committee, University of Rijeka.

Prior to any animal manipulation, all rats were housed in the controlled environment for a minimum of 7 days to eliminate stress-related influences.

The experiment was performed in two phases (Figure 1). Phase one involved the induction of unilateral MM inflammation in rats, followed by bilateral nocifensive behavioral measurements (n=16), bilateral TRG and MM tissue isolation, and subsequent quantitative real-time polymerase chain reaction (qRT-PCR) and histopathological examination of these tissues, respectively (Figure 1A). Phase two included examining the effect of unilateral P2Y2R antagonist injection on the nocifensive behavior in sham rats (Figure 1B) and in unilateral MM inflammation-induced rats (Figure 1C) (n=38).

Establishment of Bilateral Hypersensitivity Following Unilateral MM Inflammation

MM inflammation was induced by unilateral injection of complete Freund’s adjuvant (CFA, Sigma F5881, Sigma-Aldrich, Saint Louis, MO, USA; 0.5 mg/mL, heat-killed Mycobacterium tuberculosis suspended in 1:1 oil: saline emulsion), as reported in previous studies. The protocol details are described in our previous study. Briefly, rats were anesthetized with 4% isoflurane (Forane, Abbott Laboratories Ltd, Queenborough, UK) in a gas mixture O2 :N2=1:2 to abolish righting and corneal reflexes. They were then injected with 50 µL of CFA (experimental group) or 0.9% saline (control group) in the right MM mid-region. The precise administration site was determined by MM palpation between the zygomatic bone and mandible. After contacting the mandible bone, the needle was placed into the MM mid-region, and the CFA/saline was administered via a 27-gauge needle within 5–10 seconds. All solutions were freshly prepared before administration. The animals were monitored daily for evidence of edema after the CFA/saline injection. MM inflammation development was examined histopathologically, and nocifensive behavior measurements followed to confirm the development of bilateral allodynia. The inflammation and control groups each contained 8 animals (n_inflammation=8) (n_control=8).

Mechanical Nocifensive Behavior Measurements

A nocifensive behavioral response to the mechanical threshold that previously did not result in a nocifensive response was considered as a sign of mechanical hyper-sensitivity. The previously described rat head withdrawal threshold (HWT) method was used to evaluate nocifensive behavioral changes. Method details are reported in our previous study. Briefly, a von Frey anesthesiometer (VFA; type 2391, IITC Inc., Woodland Hills, CA, USA) was used bilaterally at different time points to establish the nocifensive response. The lowest force needed to cause active head withdrawal from the 1.0 mm probing tip was considered to be the HWT. The probing tip attached to the VFA was touched against the MM mid-region five times during one minute intervals, and the average value of these five measurements was defined as the HWT value. Before any VFA measurements were conducted, the rats were accustomed to stand uninhibited on the experimenter’s glove. Mechanical thresholds for evoking the head withdrawal responses were measured by bilateral MM probing before and on day 4 after CFA or saline injection, according to the results of a previous study. A baseline HWT was assessed prior to the CFA administration. Additional behavioral measurements were carried out after P2Y2R antagonist injection, as described further below. All behavioral measurements were performed by researchers blinded to the study protocol.

Tissue Isolation, Preparation, and Analysis

The final nocifensive behavioral measurements were performed 4 days post-CFA/saline injection, and rat decapitation followed. Bilateral MMs were dissected for histopathological analysis. Bilateral TRGs were harvested for qRT-PCR analysis of P2Y2 mRNA expression.

All tissue samples were frozen in liquid nitrogen and stored at −80°C until processed.
The histopathological MM tissue analysis was performed as reported in our previous study. Briefly, the entire both right and left MMs were fixed in 4% paraformaldehyde, embedded in paraffin, cut at 40 μm intervals, and stained with hematoxylin and eosin.

Quantitative real-time PCR was performed as follows. TRG tissue samples 1 cm² in size were frozen in 500 μL of RNAlater (Ambion, Austin, TX, USA) at −80°C. The tissue samples were homogenized using a MagNA Lyser instrument (Roche Life Sciences, Mannheim, Germany). Total RNA was isolated using a NucleoSpin RNA kit (Macherey-Nagel, Duren, Germany) according to the manufacturer’s instructions. A Qubit 3.0 instrument and Qubit RNA Broad Range reagent (Life Technologies, Carlsbad, CA, USA) were used to quantify the RNA concentration. Total RNA was reverse transcribed using a High-Capacity cDNA Reverse Transcription Kit (Life Technologies, Carlsbad, CA, USA). Quantitative real-time PCR was performed using a StepOnePlus real-time PCR system (Life Technologies, Carlsbad, CA, USA) with the SYBR Green Master Mix (Life Technologies, Carlsbad, CA, USA).

Figure 1 Experimental design timelines. (A) Phase one of the experiment – evaluation of CFA injection on nocifensive behavior, masseter muscle (MM) tissue histopathology and TRG tissue qRT-PCR. (B) Phase two – evaluation of AR-C118925/DMSO injection on nocifensive behavior in sham rats. (C) Phase two – evaluation of AR-C118925/DMSO administration on nocifensive behavior in unilateral MM inflammation-induced rats.

Abbreviations: CFA, complete Freund's adjuvant; HWT, head withdrawal threshold; MM, masseter muscle; TRG, trigeminal ganglion; qRT-PCR, quantitative real-time polymerase chain reaction; DMSO, dimethyl sulfoxide.
for determining the total RNA concentration. Transcription was performed using a High Capacity cDNA kit (Applied Biosystems, Foster City, CA, USA) with 500 ng of total RNA. cDNA libraries were stored at −25°C prior to the quantification process. Random hexamer primers provided with the kit were used for reverse transcription. Specific mRNA expression levels for the P₂Y₂ gene were defined using a 7500 Fast Real-Time PCR (Applied Biosystems). The primers used for qRT-PCR were from the Taqman Gene Expression Assay (Applied Biosystems) for P₂Y₂ (Rn00568476_m1) and for the housekeeping genes GAPDH (Rn01775763_g1) and beta-actin (Rn00667869_m1). The P₂Y₂ mRNA relative expression levels were determined by the 2-ΔΔCt method to compare its expression with those of the housekeeping genes.²⁴,²⁹,³⁰

P₂Y₂ Receptor Antagonist Administration in Sham Animals
The impact of an intramasseteric injection of the competitive and selective P₂Y₂R antagonist AR-C118925 (Tocris Bioscience, St Louis, MO, USA) on the baseline HWT was evaluated.²⁴,²⁵ The rats were lightly anesthetized with 2% isoflurane in an O₂:N₂=1:2 mixture.²⁴ AR-C118925 was then injected at a dose of either 0.2 mg/100 µL (Dlow, n=6) or 1 mg/100 µL (Dhigh, n=6). The volumes and doses of AR-C118925 were defined taking into consideration findings from a recent study.⁸ The same volume (100 µL) of dimethyl sulfoxide (DMSO)(Sigma-Aldrich) was administered to the control group animals (n=6). Behavioral measurements were performed prior to the AR-C118925/DMSO injection and at 15, 30, 60, 90, and 120 minutes after the AR-C118925/DMSO administration.²⁴,²⁵,³¹

P₂Y₂ Receptor Antagonist Administration in the Inflammation Group
The impact of AR-C118925 or DMSO administration into the MM on bilateral HWT in animals with CFA-induced unilateral MM inflammation (the inflammation group) was subsequently estimated.²⁴,²⁵ The inflammation induction and antagonist administration protocols are reported in our previous study.²⁴ Briefly, the baseline HWT was evaluated. The rats were subsequently anesthetized with 4% isoflurane and unilaterally injected with CFA. On day 4 after the intramasseteric CFA injection, bilateral HWT was measured to confirm the development of bilateral mechanical allodynia. After the behavioral evaluation, each animal was lightly anesthetized with 2% isoflurane and AR-C118925 was injection at a dose of either 0.2 mg/100 µL (Dlow, n=6) or 1 mg/100 µL (Dhigh, n=6). Control animals were injected with 100 µL of DMSO (n=6). The volumes and doses of AR-C118925 were defined taking into consideration the results of a recent study.⁸ All solutions were freshly prepared before use. P₂Y₂ antagonist was injected unilaterally to the mid-region of the right MM, as described above. The HWT was measured 15, 30, 60, 90, and 120 minutes after the AR-C118925/DMSO injection.²⁴,²⁵,³¹

Statistical Analysis
The results were analyzed using SPSS 21.0 software (SPSS Inc., Chicago, USA). The data are presented as the means ±standard error of the mean (SEM). The Kolmogorov–Smirnov test was used to test the normality of distribution of all measurements. The independent samples t-test was utilized to establish the differences in nociceptive behavior before and after the CFA/saline injection. The one sample t-test was used to analyze the differences in P₂Y₂ mRNA expression between the two groups. Mechanical HWT measurements between the inflammation and control groups injected with AR-C118925/DMSO were assessed using mixed ANOVA, with time points as a within-subjects factor and the group as a between-subjects factor. Significance was defined as p<0.05. The results are presented graphically.

Results
CFA Injection Caused Ipsilateral Inflammation in the Rat MM
The unilateral administration of CFA into the right MM mid-region produced redness and edema around the site of administration. MM contralateral to the site of CFA administration and bilateral MMs in control rats showed no signs of inflammation.

The histological signs of massive granular leukocyte infiltration and the large number of vacuoles present in the CFA-administered MM unequivocally confirmed the development of inflammation (Figure 2A). Neither the contralateral MM in CFA-administered animals (Figure 2B) nor the MMs of control rats showed any histological signs of inflammation (Figure 2C).

MM Inflammatory Hypersensitivity Was Related to Up-Regulated P₂Y₂ Expression in the TRG
qRT-PCR analysis of the P₂Y₂ receptors mRNA expression levels in bilateral TRGs isolated on day 4 after
unilateral intramuscular inflammation induced showed statistically significant enhancement of P$_2$Y$_2$ mRNA expression in the TRG ipsilateral to inflamed MM compared to the control group (p=0.011) (Figure 3A). In the contralateral MMs, no significant difference in P$_2$Y$_2$ mRNA expression was detected in comparison to the control animals (p=0.647) (Figure 3B).

**Unilateral Intramuscular Administration of AR-C118925 Had No Effect on Baseline HWT in Sham Animals**

To rule out the possible effect of the antagonist injection on the baseline HWT, AR-C118925 or DMSO were unilaterally injected into the MMs of sham rats. The tested doses of AR-C118925 (D$_{low}$ and D$_{high}$) and DMSO were unable to provoke any changes to the baseline HWT in sham rats at any observed time point (15, 30, 60, 90, and 120 after injection) (Figure 4A and B). Neither ipsilateral nor contralateral differences were established between groups at any observed time point (Figure 4A and B).

**Unilateral Intramuscular Administration of AR-C118925 Alleviated Bilateral MM Hypersensitivity in Inflammation Group of Animals**

AR-C118925 injected ipsilaterally to the CFA injection site resulted in a statistically significant increase in ipsilateral HWT in both the D$_{low}$ and D$_{high}$ inflammation groups compared to the DMSO group at 30, 60, 90, and 120 minutes after the AR-C118925/DMSO injection (p≤0.001). HWT measurement values obtained 15 minutes after antagonist administration showed no significant pain attenuation in the D$_{low}$ and D$_{high}$ groups (Figure 5A).

Contralateral to CFA and AR-C118925/DMSO administration site, the statistical test revealed significant HWT increase in D$_{low}$ and D$_{high}$ inflammation groups compared to controls 30, 60, 90, and 120 minutes after AR-C118925/DMSO injection (p≤0.001). No significant HWT increase was observed 15 minutes after antagonist injection in both the D$_{low}$ and D$_{high}$ groups (Figure 5B).

**Discussion**

The role of P$_2$Y$_2$Rs in bilateral muscular orofacial pain is poorly understood. Furthermore, the mechanism involved in pain transmission and the expression pattern of pain receptors in neurons in the dorsal root ganglion (DRG) and the TRG differ according to pain location. Therefore, this experimental design was established to assess the possible changes in P$_2$Y$_2$R expression in bilateral MM inflammatory hypersensitivity in the TRG and to test the effect of selective and competitive P$_2$Y$_2$R antagonist AR-C118925 on the nocifensive behavior induced by unilateral injection of CFA into the MM.

Some studies have suggested the involvement of P$_2$Y$_2$Rs in trigeminal pain, although their role is not yet clear. Ando et al have reported that the administration of UTP, a potent P$_2$Y$_2$R agonist, resulted in mechanical allodynia attenuation in a bilateral neuropathic pain model, but it had only ipsilateral analgesic effect in plantar acute pain
Conversely, another study found that the administration of P2Y2R antagonist AR-C118925 was followed by a complete blockage of satellite glial cell activation and had a long-lasting analgesic effect in facial allodynia induced by CFA administration into the temporomandibular joint.

A recent study on chronic constriction injury of the infraorbital nerve as a neuropathic trigeminal pain model showed dose- and time-dependent analgesic effects of P2Y2R antagonists.

Several studies have reported P2Y2R expression changes in inflammatory pain states that affect different body parts, but no study has investigated TRG P2Y2R expression levels in an inflammatory MM pain model. Malin et al found that P2Y2Rs are the only Gq P2YR that are up-regulated in DRG neurons in inflammatory conditions. Magni et al established an in vivo inflammatory temporomandibular joint pain model that resulted in satellite glial cell activation and enhanced P2Y2R expression ipsilateral to the inflammation site. As mentioned above, the expression patterns of pain receptors in the TRG and DRG and the pain transmission pathways seems to vary depending on the site of pain onset.
However, no study has yet investigated the expression of $P_2Y_2Rs$ in the TRG using an inflammatory MM model. Our qRT-PCR analysis revealed a statistically significant up-regulation of $P_2Y_2R$ mRNA expression in the TRG ipsilateral to MM inflammation, suggesting a direct relationship between MM inflammation and ipsilateral increased $P_2Y_2R$ expression (ie ipsilateral hypersensitivity and increased $P_2Y_2R$ expression are positively correlated). The lack of $P_2Y_2R$ mRNA expression changes contralateral to the MM inflammation suggests that $P_2Y_2Rs$ are not likely to have a direct impact on the development of peripheral non-inflammatory pain.

Behavioral measurements were performed before and after CFA and AR-C118925 were injected to assess possible changes in pain sensation. In accordance with recent studies, AR-C118925 was chosen for blockage of the up-regulated $P_2Y_2Rs$. The results of the current study showed attenuation of bilateral hypersensitivity after AR-C118925 was administered ipsilateral to the inflammation. This suggests that the analgesic effect of AR-C118925 on ipsilateral MM hypersensitivity may be mediated by its effect on $P_2Y_2Rs$. A possible contralateral hypersensitivity mechanism implicates $P_2Y_2R$ up-regulation ipsilateral to the site of inflammation, followed by a second messengers
cascade and activation of certain central nervous system (CNS) structures, resulting in contralateral hypersensitivity. As previous studies suggest the importance of satellite glial cells in pain transmission, neuron-glia interaction may also be taken into consideration in explaining a contralateral hypersensitivity mechanism. Neuron-glia interaction in the TRG possibly has a crucial impact on neuronal and glial function within CNS structures in increased and abnormal afferent activity in orofacial inflammatory nociception processes. There is evidence that non-synaptically released chemical mediators from neurons and satellite glia may induce chronic pain via autocrine and/or paracrine mechanisms and that augmented excitability of primary afferent neurons results in changes in central pain-signaling neurons (central sensitization). Our results show that P2Y2Rs are important in hypersensitivity onset that occurs both ipsilateral and contralateral to the site of inflammation. Our findings show that inflammation can trigger up-regulated P2Y2R expression in primary neurons ipsilateral, but not contralateral to the inflammation. The increased P2Y2R expression can be directly related to ipsilateral hypersensitivity. It is possible that a neuronal cascade induces a contralateral

Figure 5 The effect of unilateral administration of AR-C118925 or dimethyl sulfoxide (DMSO) on head withdrawal threshold (HWT) in rats injected with complete Freund’s adjuvant (CFA). (A) The effect on HWT of ipsilateral CFA and AR-C118925/DMSO injection. (B) The effect on HWT of contralateral CFA and AR-C118925/DMSO injection.

Notes: *p<0.05, **p<0.01 for Dlow group, ^p<0.05, ^^p<0.01, ^^^p<0.001 for Dhigh group.

Abbreviations: DMSO, dimethyl sulfoxide; HWT, head withdrawal threshold; CFA, complete Freund’s adjuvant; Dlow, 0.2 mg/100μL dose of AR-C118925; Dhigh, 1 mg/100μL dose of AR-C118925.
hypersensitivity response that is not directly connected to changes in \( P_2Y_2R \) expression in primary neurons.

There are some limitations of this study. The role of \( P_2Y_2R \)s was investigated only at TRG level solely (and not at the level of MM or CNS structures). In addition, the \( P_2Y_2R \) expression levels were assessed in the entire TRG, while only a limited number of neurons innervating the MM were influenced by the CFA injection.

Conclusions

Our findings indicate that \( P_2Y_2R \)s may functionally influence MM hypersensitivity. \( P_2Y_2R \) up-regulation in TRG neurons ipsilateral to MM inflammation appears to be involved in ipsilateral inflammatory MM hypersensitivity. By contrast, contralateral hypersensitivity shows a non-inflammatory phenomenon that is not likely to be directly related to changes in \( P_2Y_2R \) expression.

Data Sharing Statement

The data and materials, as well as the raw data, are available by contacting the corresponding author.

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Author Contributions

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; gave final approval of the version to be published; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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