Brain to Bedside: Using Neuroscience to Cultivate Empathy in Medicine

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***Abstract*—Much has been written about the "empathy-deficit" among medical students, residents, and physicians, and the resulting (negative) effects on patients. While various proposals to counter the erosion of empathy throughout medical education and practice have been offered, to our knowledge no one has looked to map what we know about how the brain processes various kinds of empathy (affective, cognitive, etc.) to particular kinds of pedagogy (role play, simulation, didactic, etc.). For example, in cognitive empathy crucial brain regions involved include the ventral TemporoParietal Junction (TPJ), Superior Temporal Sulcus (STS), temporal poles, medial PreFrontal Cortex (mPFC) and precuneus/posterior cingulate. The TPJ has shown to mediate transient mental inferences about others such as about their goals, desires, and beliefs, while the mPFC facilitates attribution of more enduring traits about self and others. Our research indicates that to strengthen this trait narrative medicine and mindfulness training work better than, say, role play, which is better suited to the neural processes associated with affective empathy. In this review, we examine the neuroanatomical and chemical bases of empathy and discuss how these insights might well inform medical curricula. Integrating neuroscience and pedagogy allows for empathy to be cultivated in ways that are both scientifically grounded and clinically sustainable.**

Keywords - Empathy; Narrative medicine; Neuroscience; Compassion.

I. INTRODUCTION

Empathy, or the capacity to resonate with, understand, and respond to the mental and emotional states of others, is a multidimensional construct with critical relevance to neuroscience, clinical care, and medical education. Understanding these dimensions may lay the foundation for enhancing the delivery of compassionate and quality medical care.

Empathy is a fundamental component of connecting with others. Physicians have been consistently shown to drop in empathy scores as they move through medical school and into practice. Despite recent attention, empathy is still often an overlooked and deprioritized element of medical training, with consistently low empathy scores in physicians from training into practice [1]-[3], attached to the conventional thought that empathy is intrinsic rather than a teachable skill [4]. Yet, different aspects of empathy have been shown to be teachable, and it is a crucial ability to hone for building trust between patients and providers. Once built, this trust can serve as the catalyst for effective shared decision-making and improved patient outcomes [5]-[12].

Types of empathy include affective (resonance), cognitive (Theory of Mind (ToM)), and empathetic concern (compassion). Here, we elaborate on these types, examine the neuroanatomical and chemical bases of empathy, and discuss how these insights may inform medical curricula. Integrating neuroscience and pedagogy allows for empathy to be cultivated in ways that are both scientifically grounded and clinically sustainable.

We conducted a narrative review about empathy, neural correlates of empathy, and proposed approaches to teaching empathy leveraging these correlations. We searched for pertinent scientific literature without restricted dates, focusing on rigorous meta-analyses, review papers, and randomized controlled trials with an emphasis on recent studies with higher impact that presented robust evidence-based findings.

II. FOUNDATIONS IN NEUROSCIENCE

Most areas of the supratentorial (cerebrum), and to a lesser extent the infratentorial (brainstem, cerebellum) brain have been shown to be utilized in empathy, with heavy involvement of limbic and paralimbic networks in frontal, temporal, and parietal lobes. Neural networks are mediated by a mirror neuron system in which action perception is coupled to action execution through two main cortical networks. The first of these networks is formed by the parietal and premotor cortices, and the second by the Anterior Cingulate Cortex (ACC) and insula [13].

A. Neural Circuits

Mirror neurons may form the cellular basis for empathy. Initially found in rats and macaque monkeys, these neurons pave the way for perception-action coupling (understanding-based simulation) [14], [15]. Mirror neuron systems span sensorimotor and emotional neural networks, and may also include the basal ganglia and cerebellum [16]. The sensorimotor regions involved are the ventral PreMotor cortex (PMv), primary Motor cortex (M1), Inferior Parietal Lobe (IPL), Anterior Intraparietal Area (AIP) dorsal and mesial PreMotor cortices (PMd, PMm), PreFrontal Cortex (PFC), and the secondary Somatosensory cortex (SII). Emotional neural networks span limbic and paralimbic centers including the Anterior Cingulate Cortex (ACC), amygdala, and Anterior Insula (AI).

The perception of emotion in others activates mirror neurons in the Inferior Frontal Gyrus (IFG, Brodmann's Area BA 45/44/6) and Inferior Parietal Lobe (IPL, BA 39, 40) in coordinating first-hand emotional experiences, eliciting a corresponding automatic motor response [17]. The IFG identifies goals or intentions of actions by their resemblance to stored representations of these actions [13]. The amygdala facilitates recognition of facial emotions in others [18].

Conceptual frameworks distinguish empathy as affective (resonance), cognitive (Theory of Mind (ToM)), and as empathetic concern (compassion). These domains are dynamically interactive, with partially overlapping neural substrates [15][17][19][20]. Affective empathy is the capacity to emotionally react to another's mental state, and usually involves the interrelated unconscious processes of emotional recognition, contagion, and shared pain [21]. The IPL and IFG have been consistently shown to be activated in emotional contagion, and AI and ACC in the shared pain network [15][17][22].

Cognitive or ToM empathy refers to the capacity to use cognitive processes to take the perspective of others, make inferences, and predict the emotional and mental states of others. Rather than centering around emotion, ToM infers knowledge about another's beliefs, thoughts or emotions. Crucial brain regions involved include the ventral TemporoParietal Junction (vTPJ), Superior Temporal Sulcus (STS), temporal poles, medial PreFrontal Cortex (mPFC), and precuneus/posterior cingulate [17][23]. The TPJ has shown to mediate transient mental inferences about others such as about their goals, desires, and beliefs, while the mPFC facilitates attribution of more enduring traits about self and others [17].

Empathetic concern is defined as a compassionate response elicited by witnessing someone else in need [24]. This empathy type is regarded as a complementary social emotion related to feelings of concern and support. Neural networks implicated include the Ventral Striatum (VS) including the nucleus accumbens, Ventral Tegmental Area (VTA), medial OrbitoFrontal Cortex (mOFC) and the subgenual Anterior Cingulate (sgACC). Congruently with these activations in reward- and affiliation-associated networks, compassion generates positive affect towards others' suffering [23][25][26].

Though we distinguish these types of empathy, it's plausible that the empathetic response incites them synchronously, with different components being evoked to different extents depending on the context. In fMRI brain studies, distinct but sometimes overlapping neural pathways have been found to correspond to both affective and cognitive empathy, providing evidence for the separate but related forms empathy can take [27].

B. Neurochemical Modulators

The neuropeptide oxytocin is synthesized in the hypothalamus and released both centrally in the brain and peripherally into the bloodstream. Oxytocin plays a foundational role in social bonding, attachment, and trust [28]. Mechanistically, oxytocin downregulates amygdala activity, thereby lowering social threat perception and enhancing social approach behaviors [29]. This neurochemical modulation supports cooperation, affiliation, and the capacity for emotional attunement to others. Oxytocin has been shown to be particularly linked to affective empathy [18].

Empirical studies using the Multifaceted Empathy Test have shown that intranasal oxytocin enhances self-assessed emotional empathy but not cognitive empathy [18]. Other work shows that individuals with higher endogenous oxytocin levels report greater dispositional empathy, and polymorphisms in the oxytocin receptor gene correlate with higher empathy and stress reactivity [28]. Together, these findings suggest that oxytocin's influence on empathy may primarily operate through emotional resonance, trust formation, and reduced social anxiety [29].

Dopamine is a catecholamine neurotransmitter central to motivation, reinforcement learning, and the valuation of reward. In social cognition, dopamine links ToM empathy with motivational systems that drive prosocial action [30]. High dopaminergic activity facilitates the rewarding nature of social interactions, particularly those involving understanding or helping others [31]. Lackner et al. found that dopaminergic functioning was associated with ToM development in preschoolers, suggesting a role for dopamine in early empathic cognition [30]. Genetic studies have also shown that variation in dopamine receptor genes modulate cognitive empathy and prosocial behavior [31]. Thus, dopamine supports the cognitive processes underlying cognitive empathy and links these cognitive processes to the reward system, reinforcing social behavior.

Serotonin (5-HT) modulates social emotion and behavioral regulation by influencing mood, impulsivity, and sensitivity to social feedback. 5-HT plays a central role in regulating emotional resonance or the capacity to share another's emotional state while maintaining self-regulation. Tryptophan depletion studies show that low serotonin availability amplifies social emotional responses such as guilt or anger depending on personality traits [32]. Thus, serotonin supports adaptive empathy by modulating emotional reactivity and maintaining balance between self and other emotional states.

Cortisol, the primary stress hormone, can disrupt the coupling between emotional resonance and regulatory control. High cortisol levels reduce activity in brain regions related to empathy for pain and emotional processing [33]. Conversely, endogenous opioids, particularly the μ-opioid system, mediate empathic concern, social bonding, and soothing responses. Opioid antagonism reduces empathic concern and diminishes affiliative behavior, supporting the view that endogenous opioids underpin the calming, nurturing dimensions of compassionate empathy [34].

III. LINKING NEUROSCIENCE AND CURRICULUM DESIGN

A neuroscience-informed pedagogy purposefully aligns educational interventions with neural circuits and neurochemical systems that support empathy, social cognition, and prosocial motivation (Figure 1). When mapped onto empathy neural architectures, targeted curricula

can build and refine specific capacities, producing not only behavioral improvement but also measurable neuroplastic change [35]. Correlating neural networks of empathy to didactic approaches and training enhances communication while protecting against empathic fatigue and burnout.

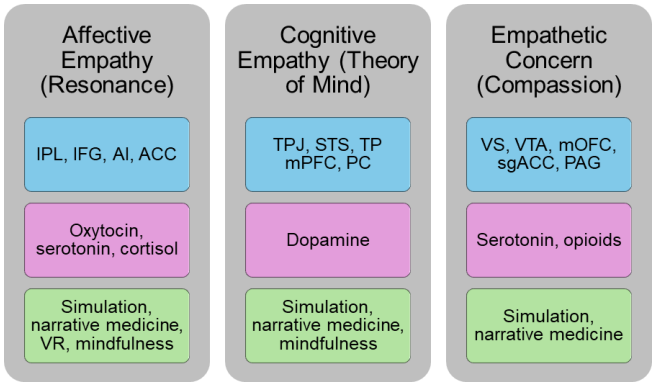

Figure 1. Overview of Neural Correlates of Empathy and Didactic Approaches; Abbreviations: Inferior Frontal Lobe (IPL); Inferior Frontal Gyrus (IFG); Anterior Insula (AI); Temporal Poles (TP); Precuneus/Posterior Cingulate (PC); PeriAqueductal Gray region (PAG).

IV. EDUCATIONAL STRATEGIES IN MEDICINE

Empathy requires the capacity to both share another's emotional experience (affective empathy) and understand another's internal state (cognitive empathy). Contemporary models emphasize three interacting components: affective sharing that supports interpersonal resonance, self–other distinction that preserves separateness, and cognitive flexibility that allows sustained attention to another while regulating self-oriented distress [15][36]. These components rely on partially dissociable but interacting neural systems, suggesting that successful empathy education integrates affective, cognitive, and compassionate processes and their regulation rather than privileging any single domain [17].

A. Principles of Curriculum Design

Effective empathy education aligns with neurodevelopmental principles of experience-dependent plasticity. Engaging in new experiences, memory training, and neurofeedback are known to enhance synaptic efficiency and functional connectivity within distributed socioemotional networks [37][38]. Spiral curriculum design, characterized by repeated engagement with core concepts at increasing levels of complexity, may support long-term potentiation within prefrontal-limbic pathways, including the medial PFC, ACC, and AI, which collectively contribute to empathic ability and emotion regulation [39]-[43].

Deliberate practice further leverages dopaminergic reinforcement learning mechanisms, wherein feedback-based learning strengthens behavior through reward prediction error signaling in the ventral striatum and its functional coupling with the frontal cortex [44][45]. These mechanisms have been implicated in the consolidation of complex social behaviors, including perspective-taking and prosocial decision-making [46].

Formative assessment can support neuroplastic integration by promoting reflective retrieval, a process that engages hippocampal–vmPFC circuitry and strengthens memory traces for context-specific behavioral scripts [47], [48]. The use of quantitative tools such as the Jefferson Scale of Physician Empathy and performance-based assessments including OSCEs remain directly unlinked to specific areas of neural activation. Yet existing knowledge about the recruitment of the TPJ and AI during perspective-taking and socioemotional evaluation tasks highlights the potential for such tools to be utilized in pedagogy [8][49][50].

B. Role-Play and Simulation

Simulation-based empathy training engages all categories of empathy circuits. Peer role-play activates regions associated with action observation and embodiment, including the IFG, IPL, and insula, core components of the mirror neuron and interoceptive systems [17][51][52]. However, peer simulations may generate limited affective salience, potentially constraining neuromodulatory engagement.

In contrast, interactions with Standardized Patients (SPs) may elicit more authentic social-emotional processing, engaging the ACC and AI, correlating with neuroendocrine markers of affiliative behavior including oxytocin release [18][53]. Though Bagacean et al. found no differences in empathy between peer- and SP-mediated role-play, the study had a low sample size and noted more appropriate communication skills with SPs [54].

High-fidelity simulations can evoke strong autonomic and limbic responses, recruiting the amygdala, insula, PeriAqueductal Gray (PAG), and brainstem autonomic nuclei involved in caregiving and threat-response integration [55] [56]. These emotionally salient experiences may enhance learning retention through dopaminergic reinforcement within the ventral striatum, a mechanism consistent with evidence that emotionally arousing learning episodes are preferentially consolidated in memory [57].

C. Narrative Medicine

Narrative medicine fosters narrative competence by engaging neural networks implicated in social imagination, autobiographical memory, and moral reasoning [58]. Functional neuroimaging demonstrates that reading and reflecting on stories activates the Default Mode Network (DMN), including the mPFC, TPJ, PCC, and angular gyrus, which substantially overlaps with ToM circuitry [59]-[62].

Narrative engagement has also been associated with activation of mesolimbic dopaminergic pathways, linking story comprehension to reward valuation and emotional meaning [63]-[65]. Reflective writing in narrative medicine supports emotional regulation, catharsis, and meaning making [58][66]. There are no direct empirical studies linking reflective emotional processing to serotonergic or endogenous opioid activity. However, adjacent research shows that emotional regulation and stress-processing, processes engaged during reflective writing, are modulated by these neurotransmitter systems [67]-[69].

Additionally, narrative that elicits empathy can enhance oxytocin-mediated social bonding, reinforcing prosocial motivation and affiliative trust [70]. Therefore, narrative medicine incorporates the neural architecture underlying empathic understanding.

D. Mindfulness and Reflective Practice

Mindfulness meditation strengthens prefrontal regulation of emotional and autonomic systems. Neuroimaging studies consistently demonstrate increased activation and functional connectivity in the dorsolateral PFC, ACC, and insula as well as reduced amygdala reactivity, reflecting enhanced interoceptive awareness and emotional regulation [71][72]. Mindfulness practices are also associated with neurochemical shifts, including enhanced GABAergic tone and reductions in cortisol and sympathetic arousal [73][74]. Emerging evidence suggests that mindfulness may also modulate dopaminergic tone in reward-related regions, including the ventral striatum, supporting intrinsic motivation and sustained prosocial engagement [75][76].

E. Digital and Immersive Technologies

There are varying views on the ability of VR as a tool to teach empathy [77]. On one hand, digital empathy interventions may recruit overlapping neural systems through immersive and emotionally salient experiences. VR simulations may enhance embodied perspective-taking by engaging the AI, ACC, TPJ, with measurable increases in affective resonance and variable impact on cognitive empathy [78]-[82]. On the other hand, VR has been critiqued as being an oversimplification of the complexities of empathy. Ethical concerns using VR and lack of rigorous research have been cited [77].

Neuroendocrine evidence indicates some immersive VR interventions can increase salivary oxytocin, and neuroimaging studies of interactive virtual environments show engagement of striatal-midbrain reward circuitry consistent with dopamine-mediated reinforcement learning. Together, these findings present a possible pathway by which immersive VR could strengthen empathy learning through heightened experiential salience [83][84]. Artificial-intelligence-driven conversational agents that provide real-time feedback on empathic markers such as facial expression, gaze, and tone may engage social learning circuits involving mPFC–striatal coupling, paralleling mechanisms observed in human social feedback processing [85]-[87].

Collectively, these digital approaches may offer scalable platforms that reflect the multisystem neural architecture of empathy, integrating affective resonance, cognitive perspective-taking, and motivational reinforcement into adaptive learning environments. More research is needed to examine causal relationships between these technologies and empathy.

F. Shielding Against Empathetic Distress

Balint groups and structured reflective dialogue add a social dimension, engaging oxytocin-mediated affiliative circuits and vmPFC–amygdala pathways implicated in empathic concern and emotional homeostasis [40][88]-[90]. These group-based reflections may help buffer stress-related neuroendocrine responses and mitigate empathic fatigue in clinicians. Compassion training may also help mitigate burnout from providing empathy and strengthen resilience through increased activations in networks spanning the ventral striatum, pregenual ACC, and mOFC [91]. Teaching the techniques of "empathetic communication" has shown promise, as way of guiding physicians to say the right thing even if their feelings are not aligned.

V. CONCLUSION

Empathy is supported by robust neural networks including the mirror neuron system, limbic, and paralimbic pathways and is modulated by neurochemicals implicated in emotional and behavioral regulation. Mapping didactic methods to this neural architecture may effectively bridge current gaps in the delivery of empathic medical care, underscoring that empathy is not static.

A multitude of evidence shows empathy, in all its forms, can be taught, reinforced, and sustained. Simulation, narrative medicine, mindfulness, and digital tools provide evidence-based methods for cultivating empathy in the practice of clinical medicine. Future research assessing the efficacy of these methods is necessary to improve upon ways of teaching the vital skillset of empathy to ultimately improve patient outcomes while enriching provider experiences.

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