

Strongly Edge Perfectly Antimagic Total Graphs: Properties, Constraints

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Abstract. Specialized graph labeling known as Strongly Edge Perfectly Antimagic Total (SEPAT) labeling guarantees different assignments throughout a graph's structure by making sure that all edge weights are greater than vertex weights. The existence or nonexistence of SEPAT labeling is examined in this study across several graph families, such as path, cycle, star, and disjoint unions of cycles. Aside from path and cycle graphs, star graphs only display SEPAT characteristics for restricted orders, and r -regular graphs with $r > 2$ cannot be labeled with SEPAT, according to the research. In addition, we show the scope and limits of SEPAT labeling by providing thorough constructs and demonstrations. This study furthers our knowledge of antimagic total labelings and paves the way for future investigations into labeling limitations in intricate graph structures.

Key words and Phrases: Strongly Vertex Perfectly Antimagic, Perfectly Antimagic, Totally Antimagic, Total labeling.

1. INTRODUCTION

Graph labeling is a fascinating area of graph theory that investigates the assignment of numerical labels to the elements of a graph under specified conditions. Throughout this paper, all graphs are assumed to be finite, simple, and undirected. A labeling function defined on the vertex set of a graph G is referred to as a vertex labeling, whereas a function whose domain is the edge set of G is called an edge labeling. A labeling function defined simultaneously on both the vertex set and the edge set of a graph G , and assigning distinct labels to all elements, is known as a total labeling. Under a total labeling, the weight of a vertex is defined as the

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sum of the labels assigned to all edges incident to that vertex. Similarly, the weight of an edge is defined as the sum of the label of the edge and the labels of its two end vertices. According to the result of M. Miller et al. [1], every graph admits a vertex antimagic total labeling. A comprehensive discussion on various labeling schemes and their properties can be found in [2]. The concept of totally antimagic total (TAT) labeling was introduced by M. Bača and M. Miller in [3].

The idea of Perfectly Antimagic Total (PAT) labeling, introduced in [4, 5], provides a refined framework in which all vertex weights and all edge weights are pairwise distinct. Building upon the concept of PAT labeling, the notions of parity-weighted graphs and strongly parity-weighted graphs were introduced in [6, 7] where the classifications are based on the parity (odd or even) of vertex and edge weights.

Subsequently, the notion of Strongly Vertex Perfectly Antimagic Total (SV-PAT) labeling was proposed in [8], where the defining condition requires that every edge weight be strictly smaller than every vertex weight. Building upon this concept, Strongly Edge Perfectly Antimagic total (SEPAT) labeling imposes the additional constraint that every edge weight exceeds every vertex weight, thereby strengthening the antimagic conditions.

This work is primarily devoted to the study of the Strongly Edge Perfectly Antimagic total (SEPAT) labeling. The SEPAT labeling possesses a distinctive and powerful structure, as it subsumes nearly all existing forms of antimagic labelings except SVPAT. In particular, the existence of a SEPAT labeling in a graph guarantees vertex antimagic, edge antimagic, totally antimagic, and perfectly antimagic properties simultaneously. Hence, once a SEPAT labeling is established, no further verification of these antimagic properties is required. The only exception arises in the case of SVPAT labeling, which is not implied by SEPAT.

This labeling framework offers valuable insight into the structural properties of graphs. In this paper, we investigate the existence and behavior of SEPAT labeling in several standard graph families, including paths, cycles, and stars. Through rigorous definitions and analytical results, we demonstrate both the applicability and the limitations of SEPAT labeling. Notably, our findings reveal that certain classes of graphs, such as r -regular graphs with $r > 2$, do not admit SEPAT labeling, highlighting the intricate relationship between graph structure and labeling constraints.

Overall, this study enhances the theoretical understanding of SEPAT labeling and establishes a foundation for further research in antimagic graph labelings. The results are supported by strong mathematical arguments and illustrative examples, offering new directions for future investigations in this area.

Abbreviations: Totally Antimagic Total (TAT), Perfectly Antimagic Total (PAT), Strongly Vertex Perfectly Antimagic Total (SVPAT), Strongly Edge Perfectly Antimagic Total (SEPAT).

2. CONSTRAINTS ON SEPAT LABELING IN r -REGULAR GRAPHS: PROPERTIES AND LIMITATIONS

In this section an r -regular graph G with Strongly Edge Perfectly Antimagic Total (SEPAT) labeling, the total weight of edges exceeds the total weight of vertices. This highlights the constraint of SEPAT labeling in maintaining edge weights strictly greater than vertex weights. We extend this restriction to r -regular SEPAT graphs ($r > 2$), where no vertex can be assigned labels from 1 to r .

Finally, no vertex in a SEPAT-labeled graph with degree greater than 1 can be assigned the label 1, as this would violate the SEPAT condition.

Theorem 2.1. *If G is r -regular SEPAT with $r \geq 2$, then*

$$\sum_{j=1}^q \alpha(e_j) < \sum_{i=1}^p (r_i - 1)\alpha(v_i).$$

Proof. Let α be the SEPAT labeling of the r -regular graph G , for $r \geq 2$, and v_i and e_j be its vertices and edges, for $1 \leq i \leq p$ and $1 \leq j \leq q$, respectively. The total weight of the vertices is less than the total weight of the edges.

$$i.e., \sum_{i=1}^p wt_{\alpha}(v_i) < \sum_{j=1}^q wt_{\alpha}(e_j)$$

for $i = 1, 2, \dots, p$ and $j = 1, 2, \dots, q$.

$$\begin{aligned} i.e., \sum_{i=1}^p \alpha(v_i) + 2 \sum_{j=1}^q \alpha(e_j) &< \sum_{j=1}^q \alpha(e_j) + \sum_{i=1}^p r_i \alpha(v_i) \\ \text{implies } \sum_{j=1}^q \alpha(e_j) &< \sum_{i=1}^p (r_i - 1)\alpha(v_i). \end{aligned}$$

□

Theorem 2.2. *Let G be a r -regular graph and $r > 2$. If G is SEPAT, then there is no vertex that assigns a label $1, 2, \dots, r$.*

Proof. Let v be the vertex that assigns a label, r then there exists an incident edge e of v and another end vertex w in G . Then

$$\begin{aligned} wt_{\alpha}(e) &= r + \alpha(e) + \alpha(w) \text{ and} \\ wt_{\alpha}(w) &= \alpha(w) + \alpha(e) + \sum_{j=1}^{r-1} \alpha(e_j). \end{aligned}$$

Since G is SEPAT, we get

$$\begin{aligned} wt_{\alpha}(e) &> wt_{\alpha}(w) \\ r + \alpha(e) + \alpha(w) &> \alpha(w) + \alpha(e) + \sum \alpha(e_j) \end{aligned}$$

$$r > \sum_{j=1}^{r-1} \alpha(e_j)$$

which is not possible. Hence, no vertex receives a label r . If the result is true for all numbers greater than 2, it is also true for all numbers less than 2. $\square$

Conjecture 2.3. *Let G represent a graph that is r -regular, with $r > 2$. If G is SEPAT, there is no edge that has the label 1.*

As a result of Theorem 2.2 and Conjecture 2.3, we are able to conclude the following conclusion:

Corollary 2.4. *If G represents a graph that is r -regular, with $r > 2$. Then G does not admit SEPAT.*

Theorem 2.5. *If G is SEPAT, then for every vertex having degree greater than 1, no vertex can label 1.*

Proof. Let α be a SEPAT labeling of a graph G and every vertex of G having degree greater than 1. Let v represent a vertex with a label of 1. Then there exists an incident edge e of v and another end vertex w in G . Then

$$\begin{aligned} wt_\alpha(e) &= 1 + \alpha(e) + \alpha(w) \text{ and} \\ wt_\alpha(w) &= \alpha(w) + \alpha(e) + \sum \alpha(e_j) \end{aligned}$$

where e_j are the incident edges of w and $j \geq 1$. Since G is SEPAT, we get

$$\begin{aligned} wt_\alpha(e) &> wt_\alpha(w) \\ 1 + \alpha(e) + \alpha(w) &> \alpha(w) + \alpha(e) + \sum \alpha(e_j) \\ 1 &> \sum \alpha(e_j) \end{aligned}$$

which is not possible. Hence, no vertex can label 1. $\square$

3. SEPAT LABELING OF PATH, CYCLE, AND STAR GRAPHS

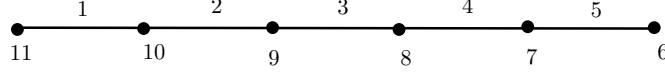
The investigation of Strongly Edge Perfectly Antimagic Total (SEPAT) labeling in different graph families is emphasized in this part, along with their distinctive characteristics and structural features.

Theorem 3.1. *Any path graph P_n with at least two vertices is a SEPAT.*

Proof. A total labeling, denoted by α , is defined for the set $V(P_n) \cup E(P_n)$ and ranges from $1, 2, \dots, 2n-1$. Assign the label $2n-i$ to the vertices v_i for all $1 \leq i \leq n$ and designate $\alpha(v_i v_{i+1})$ by i for $1 \leq i \leq n-1$.

The vertex weights are

$$\begin{aligned} wt_\alpha(v_1) &= \alpha(v_1) + \alpha(v_1 v_2) = 2n \\ wt_\alpha(v_n) &= \alpha(v_n) + \alpha(v_{n-1} v_n) = 2n-1 \\ wt_\alpha(v_i) &= \alpha(v_i) + \alpha(v_i v_{i+1}) + \alpha(v_{i-1} v_i) \end{aligned}$$

FIGURE 1. Path graph, P_6

$$= 2n + i - 1, \forall i = 2, 3, \dots, n - 1$$

Thus $wt_\alpha(v_n) < wt_\alpha(v_1) < wt_\alpha(v_i)$. For $1 \leq i \leq n - 1$, the weight of all edges are

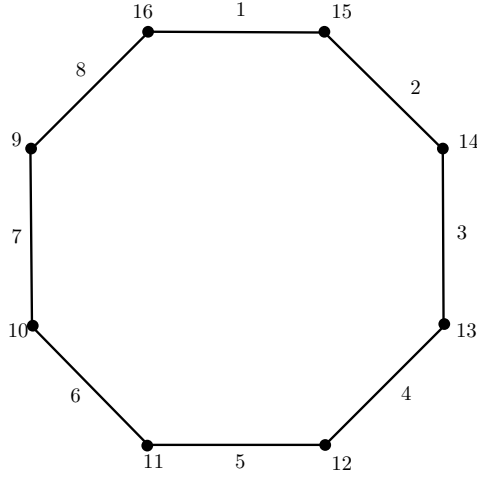
$$\begin{aligned} wt_\alpha(v_i v_{i+1}) &= \alpha(v_i) + \alpha(v_{i+1}) + \alpha(v_i v_{i+1}) \\ &= 4n - i - 1. \end{aligned}$$

From the above weights, we get the maximum vertex weight and minimum edge weight are $3n - 2$ and $3n$ respectively. $\square$

Theorem 3.2. *For any graph with at least three vertices, the cycle graph C_n is a SEPAT graph.*

Proof. Define a total labeling α on C_n by

$$\begin{aligned} \alpha(v_i) &= 2n - i + 1, \forall 1 \leq i \leq n \\ \alpha(v_i v_{i+1}) &= i, \forall i = 1, 2, \dots, n - 1 \\ \alpha(v_n v_1) &= n. \end{aligned}$$

FIGURE 2. Cycle graph, C_6

For $2 \leq i \leq n - 1$, the weight of the vertices are

$$\begin{aligned} wt_\alpha(v_1) &= \alpha(v_1) + \alpha(v_1 v_2) + \alpha(v_1 v_n) = 3n + 1 \\ wt_\alpha(v_n) &= \alpha(v_n) + \alpha(v_{n-1} v_n) + \alpha(v_n v_1) = 3n \end{aligned}$$

$$\begin{aligned}
wt_\alpha(v_i) &= \alpha(v_i) + \alpha(v_i v_{i+1}) + \alpha(v_{i-1} v_i) \\
&= 2n + i.
\end{aligned}$$

Thus $wt_\alpha(v_i) < wt_\alpha(v_n) < wt_\alpha(v_1)$. i.e, all vertex weights are distinct. The weights of all edges are

$$\begin{aligned}
wt_\alpha(v_i v_{i+1}) &= \alpha(v_i) + \alpha(v_{i+1}) + \alpha(v_i v_{i+1}) \\
&= 4n - i + 1, \forall 1 \leq i \leq n - 1 \\
wt_\alpha(v_n v_1) &= \alpha v_1 + \alpha(v_n) + \alpha(v_n v_1) = 4n + 1.
\end{aligned}$$

Thus all edge weights are distinct. From the above weights, we get the maximum vertex weight and minimum edge weight are $3n + 1$ and $3n + 2$ respectively. $\square$

Theorem 3.3. *Star graphs S_n are SEPAT iff $n \leq 3$.*

Proof. The star graph S_1 and S_2 are P_2 and P_3 respectively. It is SEPAT from thm 3.1.

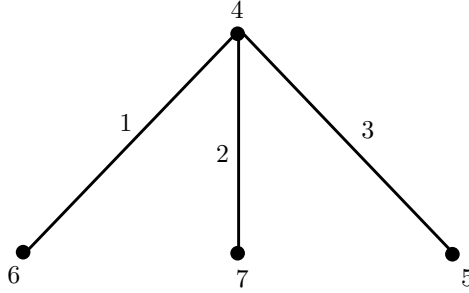


FIGURE 3. Star graph, S_3

From the Figure 3, S_3 is SEPAT.

Let's assume that α represents the SEPAT labeling for S_n , where $n \geq 4$. The vertices of graph S_n are $v_1, v_2, \dots, v_n$, with v being the center vertex. The possible minimum weight for v is $1 + 2 + \dots + n + 1$. i.e, $\frac{(n+1)(n+2)}{2}$.

The label 1 is either labelled with v or any vv_i .

Let x represent either v or vv_i , labeled with 1, and let y represent its adjacent edge or vertex (vv_i or v).

$$\begin{aligned}
i.e, \alpha(x) + \alpha(y) &= 1 + \alpha(y) \\
&= 1 + n + 1(\text{max possible label of } y) \\
&= n + 2.
\end{aligned}$$

Let e represent the edge with the label 1 or the edge next to the vertex with the label 1. Then

$$\begin{aligned}
wt_\alpha(e) &= \alpha(x) + \alpha(y) + \alpha(u_i) \\
&= n + 2 + \alpha(u_i)
\end{aligned}$$

$$\begin{aligned}
&= n + 2 + (2n + 1)(\text{max possible label of } u_i) \\
&= 3n + 3.
\end{aligned}$$

By comparing the weight of v and e , we get

$$\frac{(n+1)(n+2)}{2} \not\leq 3n+3$$

Thus, S_n does not admit SEPAT for $n \geq 4$. $\square$

Theorem 3.4. *For any positive integer $k \geq 1$ and a cycle C_t that is a SEPAT for $t \geq 3$, then there exists a k copy of C_t that is also a SEPAT graph.*

Proof. Let C_t be a cycle of order t with corresponding labeling $\alpha : V(C_t) \cup E(C_t) \rightarrow \{1, 2, \dots, 2t\}$ defined by

$$\begin{aligned}
\alpha(v_i) &= 2t + 1 - i, \forall 1 \leq i \leq t \\
\alpha(v_i v_{i+1}) &= i, \forall 1 \leq i \leq t-1 \\
\alpha(v_1 v_t) &= t.
\end{aligned}$$

Then the weights of all vertices and edges are

$$\begin{aligned}
wt_\alpha(v_1) &= 3t + 1 \\
wt_\alpha(v_i) &= 2t + i, \forall 2 \leq i \leq t-1 \\
wt_\alpha(v_t) &= 3t \\
wt_\alpha(v_i v_{i+1}) &= 4t + 1 - i, \forall 1 \leq i \leq t-1 \\
wt_\alpha(v_1 v_t) &= 4t + 1.
\end{aligned}$$

Thus, α is SEPAT labeling for C_t , for all $t \geq 3$. For $1 \leq i \leq t$ and $1 \leq j \leq k$, Let v_{ij} and $v_{ij}v_{(i+1)j}$ be the vertices and edges of the j^{th} copy of the cycle in kC_t . For $k \geq 1$, define a total labeling ω of kC_t as follows

$$\begin{aligned}
\omega(v_{ij}) &= \alpha(v_{ij}) + t(2k - 1 - j) \\
\omega(v_{ij}v_{(i+1)j}) &= \alpha(v_{ij}v_{(i+1)j}) + t(j - 1)
\end{aligned}$$

where $1 \leq i \leq t$ and $1 \leq j \leq k$.

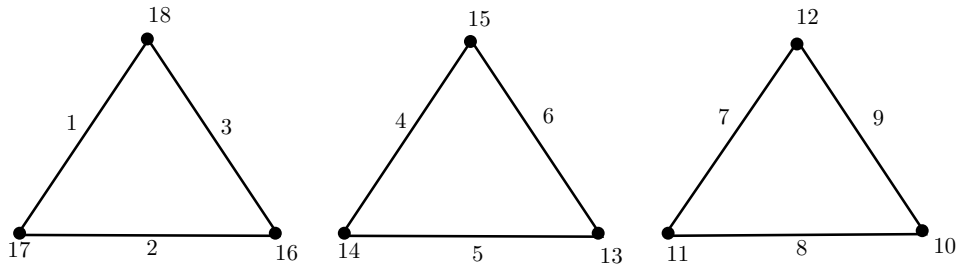


FIGURE 4. $3C_3$

For $2 \leq i \leq t-1$ and $1 \leq j \leq k$, the vertex weights are

$$\begin{aligned}
wt_\omega(v_{1j}) &= \omega(v_{(t)j}v_{1j}) + \omega(v_{1j}) + \omega(v_{1j}v_{(2)j}) \\
&= \alpha(v_{(t)j}v_{1j}) + t(j-1) + \alpha(v_{1j}) + t(2k-1-j) + \alpha(v_{1j}v_{(2)j}) + t(j-1) \\
&= wt_\alpha(v_{1j}) + t(2k-1-j) + 2t(j-1), \\
wt_\omega(v_{ij}) &= \omega(v_{(i-1)j}v_{ij}) + \omega(v_{ij}) + \omega(v_{ij}v_{(i+1)j}) \\
&= \alpha(v_{(i-1)j}v_{ij}) + t(j-1) + \alpha(v_{ij}) + t(2k-1-j) + \alpha(v_{ij}v_{(i+1)j}) + t(j-1) \\
&= wt_\alpha(v_{ij}) + t(2k-1-j) + 2t(j-1), \\
wt_\omega(v_{tj}) &= \omega(v_{(1)j}v_{tj}) + \omega(v_{tj}) + \omega(v_{(t-1)j}v_{tj}) \\
&= \alpha(v_{(1)j}v_{tj}) + t(j-1) + \alpha(v_{tj}) + t(2k-1-j) + \alpha(v_{(t-1)j}v_{tj}) + t(j-1) \\
&= wt_\alpha(v_{tj}) + t(2k-1-j) + 2t(j-1),
\end{aligned}$$

$$i.e., wt_\omega(v_{ij}) < wt_\omega(v_{tj}) < wt_\omega(v_{1j}).$$

For $1 \leq i \leq t-1$ and $1 \leq j \leq k$, the edge weights are

$$\begin{aligned}
wt_\omega(v_{ij}v_{(i+1)j}) &= \omega(v_{ij}) + \omega(v_{ij}v_{(i+1)j}) + \omega(v_{(i+1)j}) \\
&= \alpha(v_{ij}) + t(2k-1-j) + \alpha(v_{ij}v_{(i+1)j}) + t(j-1) \\
&\quad + \alpha(v_{(i+1)j}) + t(2k-1-j) \\
&= wt_\alpha(v_{ij}v_{(i+1)j}) + 2t(2k-1-j) + t(j-1), \\
wt_\omega(v_{1j}v_{tj}) &= \omega(v_{1j}) + \omega(v_{1j}v_{tj}) + \omega(v_{tj}) \\
&= wt_\alpha(v_{1j}v_{tj}) + 2t(2k-1-j) + t(j-1)
\end{aligned}$$

$$i.e., wt_\omega(v_{ij}v_{(i+1)j}) < wt_\omega(v_{1j}v_{tj}).$$

The maximum vertex weight is

$$\begin{aligned}
wt_\omega(v_{1k}) &= 3t + t(2k-1-k) + 2t(k-1) \\
&= 3tk + 1.
\end{aligned}$$

The minimum edge weight is

$$\begin{aligned}
wt_\omega(v_{(t-1)k}v_{tk}) &= 3t + 2 + 2t(2k-1-k) + t(k-1) \\
&= 3tk + 2.
\end{aligned}$$

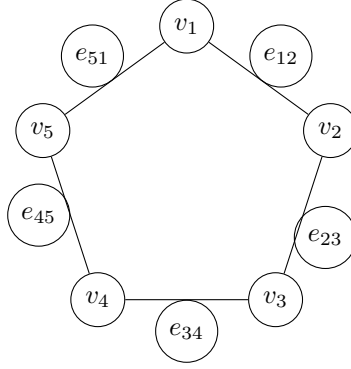
By comparing the maximum vertex weight and minimum edge weight, we can conclude that ω is SEPAT labeling of kC_t , for all $t \geq 3$ and $k \geq 1$. $\square$

4. APPLICATION IN THE NETWORK SECURITY

In a secure routing protocol, each device or system (represented as a vertex) and each communication channel (represented as an edge) need to be uniquely distinguishable to prevent misrouting or unauthorized access. A PAT labeling guarantees that no two entities have the same operational weight, whether vertices or edges.

Example: Secure Key Distribution Using SEPAT Labeling. Consider a network of five devices A, B, C, D, E , modeled as a graph $G = (V, E)$, where: $V = \{v_1, v_2, v_3, v_4, v_5\}$, $E = \{e_{12}, e_{23}, e_{34}, e_{45}, e_{51}\}$. This is a cycle graph C_5 . Suppose G is labeled such that it admits a **SEPAT labeling**:

5. GRAPH REPRESENTATION



Assign the following labels:

$$\begin{aligned}
 f(v_1) &= 10, & f(e_{12}) &= 1, \\
 f(v_2) &= 9, & f(e_{23}) &= 2, \\
 f(v_3) &= 8, & f(e_{34}) &= 3, \\
 f(v_4) &= 7, & f(e_{45}) &= 4, \\
 f(v_5) &= 6, & f(e_{51}) &= 5
 \end{aligned}$$

Edge Weights (Session Keys)

$$\begin{aligned}
 w(e_{12}) &= f(v_1) + f(e_{12}) + f(v_2) = 10 + 1 + 9 = 20 \\
 w(e_{23}) &= 9 + 2 + 8 = 19 \\
 w(e_{34}) &= 8 + 3 + 7 = 18 \\
 w(e_{45}) &= 7 + 4 + 6 = 17 \\
 w(e_{51}) &= 6 + 5 + 10 = 21
 \end{aligned}$$

All edge weights are unique, hence suitable for use as **secure session keys** between each device pair.

Security Implications.

Each communication link is uniquely identified by a session key derived from the SEPAT labeling. Even if one link is compromised, other keys remain secure due to non-redundant weights. Anomalous communications (e.g., incorrect weights) can be flagged, enabling basic intrusion detection.

Each edge weight can now act as a shared session key for secure communication between devices. Since no two edges share the same key, even if an attacker compromises one link, the others remain secure. If a node is compromised and sends

data using an incorrect edge weight, it will be detected as an anomaly, supporting intrusion detection

CONCLUDING REMARKS

This paper addresses the notion of Strongly Edge Perfectly Antimagic Total (SEPAT) labeling in different graph families, such as pathways, cycles, stars, and disjoint unions of cycles. Our results show that route and cycle graphs always have SEPAT features, whereas star graphs only have SEPAT for certain circumstances when $n \leq 3$. Noteworthy structural limits are shown by the fact that a r -graph with $r > 2$ do not permit SEPAT labeling.

Both theoretical and practical implications are offered by the results, which highlight the complex link between graph structure and SEPAT labeling. Further study on labeling limits and uses in complicated graph configurations may be built upon the basis laid forth in this work.

To encourage further exploration, we propose an open problem.

Open problem: Let G be any graph with at least one vertex that has a degree greater than 3; then G does not admit SEPAT labeling.

Data Availability Statement. Data sharing is applicable to this article, and details or supporting files are available from the corresponding author upon reasonable request.

Conflict of Interest. The authors declare no conflict of interest.

Author Contributions. **Balasundar Samipillai:** Conceptualized the problem and drafted the primary proofs. **Jeyabalan Ramasamy:** Contributed to theoretical refinements and comparative analysis. **Grienggrai Rajchakit:** Performed computational verifications and validated the graph structures. **Swathi Pitchai:** Provided administrative oversight, overall supervision, and finalized manuscript editing.

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