



*Every Second Counts!™*

**Mavrilimumab  
COVID-19 Pneumonia and  
Hyperinflammation**

# Forward Looking Statements

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# Mavrilimumab: Potential Treatment of COVID-19 Pneumonia and Hyperinflammation

## Mechanism

- GM-CSF is a key growth factor and cytokine in autoinflammation and autoimmunity<sup>1</sup>
- Mavrilimumab is a monoclonal antibody inhibitor targeting GM-CSFR $\alpha$

## Rationale

- GM-CSF is implicated in the mechanism of excessive and aberrant immune cell infiltration and activation in the lungs thought to contribute significantly to mortality in COVID-19<sup>2</sup>
- Robust literature evidence showing a consistent immunophenotype and pathology of ARDS across inflammatory/infectious etiologies (influx of neutrophils and upregulation of immature, pro-inflammatory macrophages)<sup>3</sup>

## Clinical Data

- Evidence of treatment response with mavrilimumab observed in an open-label treatment protocol in Italy in 13 non-mechanically ventilated patients with severe COVID-19 pneumonia and hyperinflammation<sup>4</sup>

## Differentiation

- Mavrilimumab is believed to be the only GM-CSF receptor blocker; other anti-GM-CSF therapeutic approaches inhibit the ligand
- GM-CSFR $\alpha$  blockade potentially prevents pathogenic cells from infiltrating into the target tissue, and suppresses multiple markers of inflammation (e.g., IL-2R $\alpha$ , IL-6, CRP)<sup>5,6,7</sup>
- Once hyperinflammation and CRS have begun, anti-virals may be less effective<sup>8</sup>
- Vaccines likely to provide incomplete population immunity + limited supply/access; vaccine does not help once virus occurs<sup>9</sup>

## Development Status

- The safety of mavrilimumab has been evaluated in a Phase 2 trial: Mavrilimumab was dosed in over 550 patients with rheumatoid arthritis through Phase 2b by MedImmune in Europe and achieved prospectively-defined primary safety and efficacy endpoints
- Enrolling and dosing patients in the global, randomized, double-blind, placebo-controlled Phase 2 portion of an adaptive design Phase 2/3 clinical trial of mavrilimumab in severe COVID-19 pneumonia and hyperinflammation

1) Wicks, Roberts, Nature Review Immunology, 2015; Hamilton, Expert Review of Clinical Immunology, 11:4, 457-465; 2) Zhou et al. bioRxiv. 2020; 3) Huang et al. 2018; Huang et al 2005; Rosseau et al 2000; Thompson et al., NEJM 2017; 4) Data as of 4/28/2020; 5) De Alessandris et al., J Leukoc Biol. 2019; 6) Sterner et al., Blood 2019; 7) Guo et al., Rheumatology 2017; 8) Darwish, Muvareka, Liles. Expert Rev. Anti Infect: Ther. 9(7), 2011; 9) Osterholm et al., The Lancet Infectious Diseases, 2012; ARDS = Acute Respiratory Distress Syndrome; CRS = Cytokine Release Syndrome

# Emerging Literature Support Rationale for Mavrilimumab in COVID-19

1 Aberrant pathogenic GM-CSF<sup>+</sup> T cells and inflammatory CD14<sup>+</sup>CD16<sup>+</sup> monocytes  
2 in severe pulmonary syndrome patients of a new coronavirus  
3  
4 Yonggang Zhou<sup>1,2,3\*</sup>, Binjing Fu<sup>1,2,4</sup>, Xiaohu Zheng<sup>1,2,4</sup>, Dongsheng Wang<sup>3</sup>, Changcheng Zhao<sup>3</sup>, Yingjie Qi<sup>3</sup>, Rui  
5 Sun<sup>1,2</sup>, Zhigang Tian<sup>1,2</sup>, Xiaoling Xu<sup>3,4</sup>, Haiming Wei<sup>1,2,4,\*</sup>  
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7 1. Institute of Immunology and the CAS Key Laboratory of Innate Immunity and Chronic Disease, School of Life  
8 Science and Medical Center, University of Science and Technology of China, Hefei, Anhui 230001, China  
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10 Hefei, Anhui 230001, China  
11 3. The First Affiliated Hospital of USTC, Division of Life Sciences and Medicine, University of Science and  
12 Technology of China, Hefei, Anhui, 230001, China  
13 4. Lead Contact  
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15 \*.Correspondence: ustcwlm@ustc.edu.cn (H.W.); xxlahh8@ustc.edu.cn (X.X.)

- Recent data provide scientific rationale implicating GM-CSF in the mechanism of excessive and aberrant immune cell infiltration and activation in the lungs thought to contribute significantly to mortality in the disease.
- The emerging data indicate that patients with COVID-19 have elevated serum levels of pro-inflammatory cytokines, including GM-CSF, and interferon-gamma, which are thought to be drivers of a cytokine storm that plays a significant role in clinical complications and acute lung injury.
- Infiltration of immune cells in the lungs of COVID-19 patients, as part of an exaggerated immune response despite falling viral loads, results in severe lung complications.
- These data suggest that it may be the excessive, non-effective host immune response by pathogenic T cells and inflammatory monocytes that causes the severe lung pathology most often associated with mortality.



# Mavrilimumab Treatment Protocol in COVID-19 Pneumonia and Hyperinflammation

Improved clinical outcomes compared to matched contemporaneous controls, including earlier weaning from supplemental oxygen, shorter hospitalizations, and no deaths

**The mavrilimumab open-label treatment protocol was a prospective, interventional, single-active-arm, single-center pilot experience in Italy.**

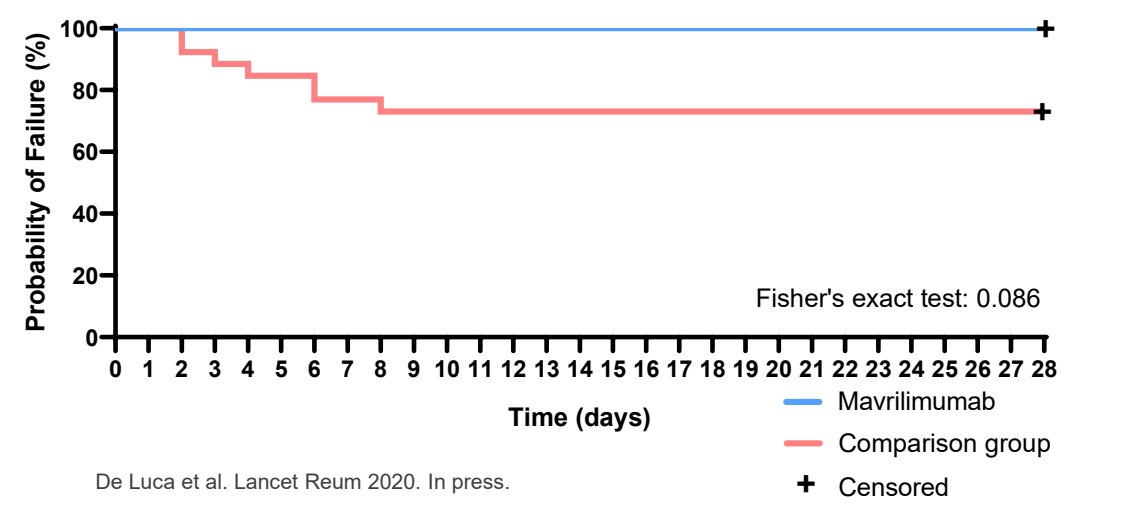
- Thirteen non-mechanically ventilated patients with severe COVID-19 pneumonia and hyperinflammation were treated with a single intravenous dose of mavrilimumab upon admission to the hospital.
- Twenty-six contemporaneous non-mechanically ventilated patients with severe COVID-19 pneumonia and hyperinflammation and with similar characteristics upon admission to the hospital, including comorbidities, baseline inflammatory markers and respiratory dysfunction, were evaluated as a control group.
- All patients in the treatment protocol received optimum local standard of care, including protease inhibitors and antiviral therapies.

**Main outcome:** Time to clinical improvement (defined as improvement  $\geq 2$  categories on a 7-point scale for assessment of clinical status)

## **Clinical Outcomes:**

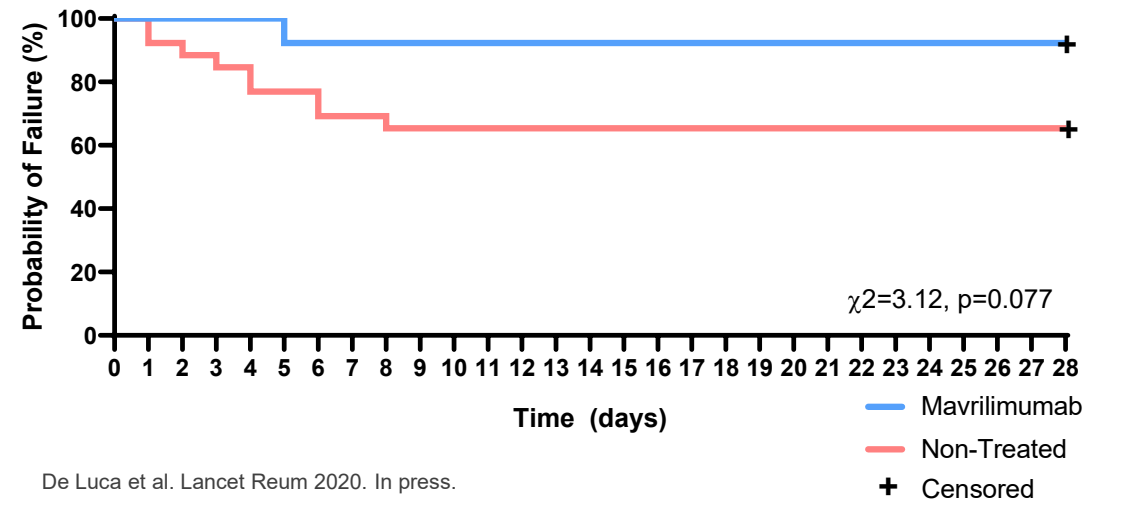
- Over the course of the 28-day follow-up period, mavrilimumab-treated patients experienced greater and earlier clinical improvements than control-group patients, including earlier weaning from supplemental oxygen, shorter hospitalizations, and no deaths.
  - Death occurred in 0% (n=0/13) of mavrilimumab-treated patients by Day 28, compared to 27% (n=7/26) of control-group patients (p=0.086).
  - 8% (n=1/13) of mavrilimumab-treated patients progressed to mechanical ventilation by Day 28, compared to 35% (n=9/26) of control-group patients who progressed to mechanical ventilation or died (p=0.077).
  - 100% (n=13/13) of mavrilimumab-treated patients and 65% (n=17/26) of control-group patients attained the clinical improvement endpoint (defined as improvement of  $\geq 2$  categories on a 7-point scale for assessment of clinical status) by Day 28 (p=0.0001).
  - Fever resolved in 91% (n=10/11 febrile patients) of mavrilimumab-treated patients by Day 14, compared to 61% (n=11/18 febrile patients) of control-group patients (p=0.0093).
  - Representative mavrilimumab-treated patients showed significant improvement in lung opacification on computerized tomography (CT) scans, consistent with the overall improvement in their clinical status.
- Mavrilimumab was well-tolerated in all patients, without infusion reactions. P-values above are unadjusted for multiplicity.

# Mavrilimumab Treatment Protocol in Patients with COVID-19 Pneumonia & Hyperinflammation Showed Improved Clinical Outcomes Compared to Matched Contemporaneous Controls<sup>1</sup>



Patients at Risk	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Mavrilimumab	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Comparison group	26	26	26	24	23	22	22	20	20	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19

Death occurred in 0% (n=0/13) of mavrilimumab-treated patients by Day 28, compared to 27% (n=7/26) of control-group patients (p=0.086)



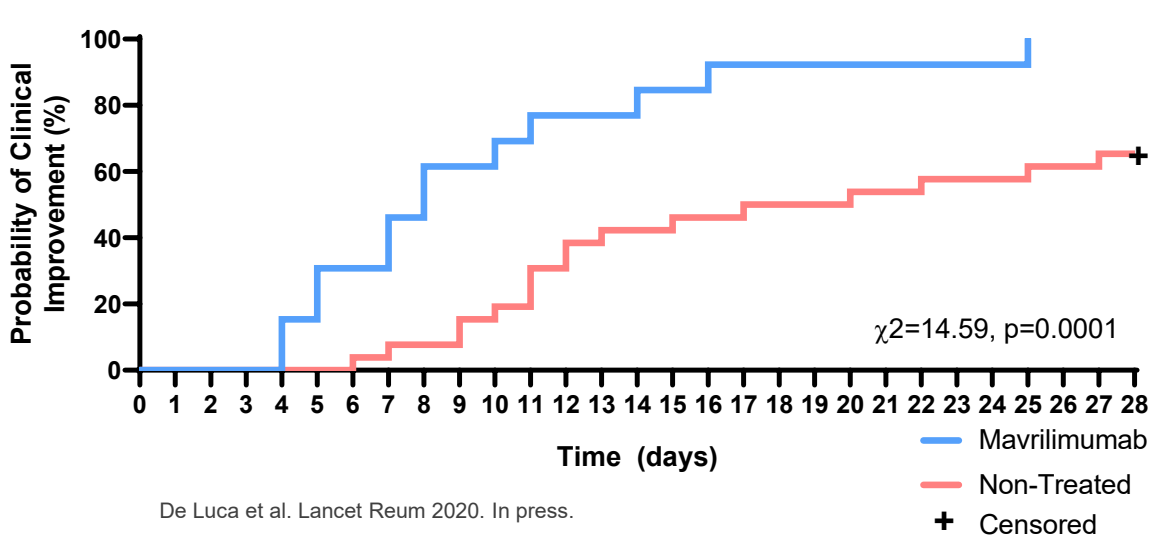
Patients at Risk	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Mavrilimumab	13	13	13	13	13	13	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Comparison group	26	26	24	23	22	20	20	18	18	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17

8% (n=1/13) of mavrilimumab-treated patients progressed to mechanical ventilation by Day 28, compared to 35% (n=9/26) of control-group patients who progressed to mechanical ventilation or died (p=0.077)

1) The treatment protocol with the investigational drug mavrilimumab was conducted by Professor Lorenzo Dagna, MD, FACP, Head, Unit of Immunology, Rheumatology, Allergy and Rare Diseases IRCCS San Raffaele Scientific Institute and Vita-Salute San Raffaele University in Milan, Italy within a COVID-19 Program directed by Professor Alberto Zangrillo, Head of Department of Anesthesia and Intensive Care of the Scientific Institute San Raffaele Hospital and Professor in Anesthesiology and Intensive Care, Università Vita-Salute San Raffaele; p-values above are unadjusted for multiplicity.

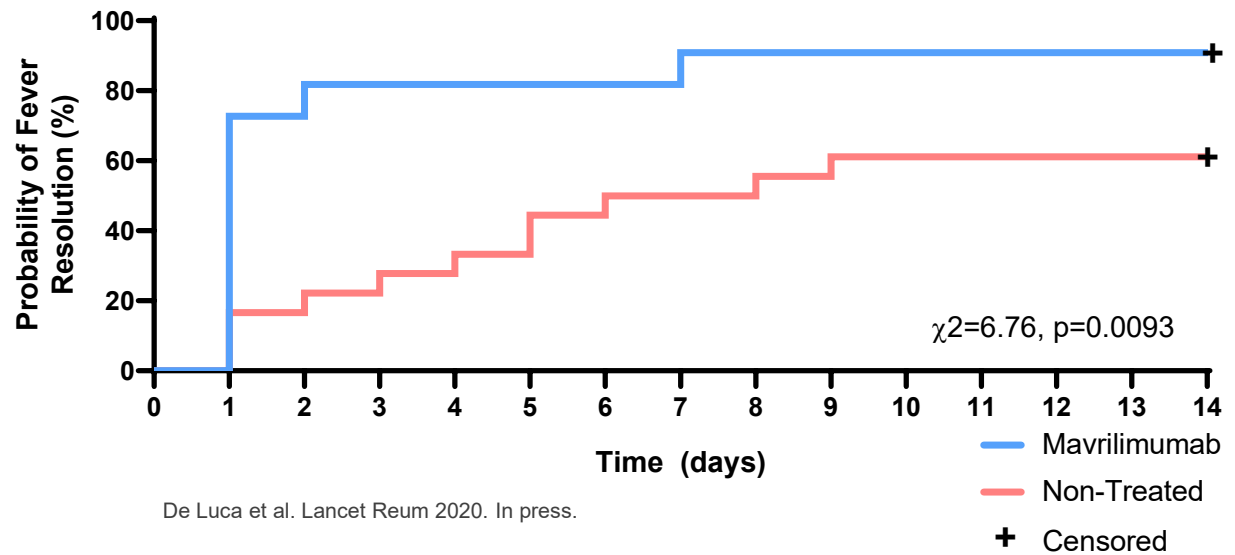


# Mavrilimumab Treatment Protocol in Patients with COVID-19 Pneumonia & Hyperinflammation Showed Improved Clinical Outcomes Compared to Matched Contemporaneous Controls<sup>1</sup>



Patients at Risk	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Mavrilimumab	13	13	13	13	13	11	9	9	7	5	5	4	3	3	3	2	2	1	1	1	1	1	1	1	1				
Comparison group	26	26	26	26	26	26	26	25	24	24	22	21	18	16	15	15	14	14	13	13	13	12	12	11	11	10	10	9	

100% (n=13/13) of mavrilimumab-treated patients and 65% (n=17/26) of control-group patients attained the clinical improvement endpoint (defined as improvement of  $\geq 2$  categories on a 7-point scale for assessment of clinical status) by Day 28 (p=0.0001)

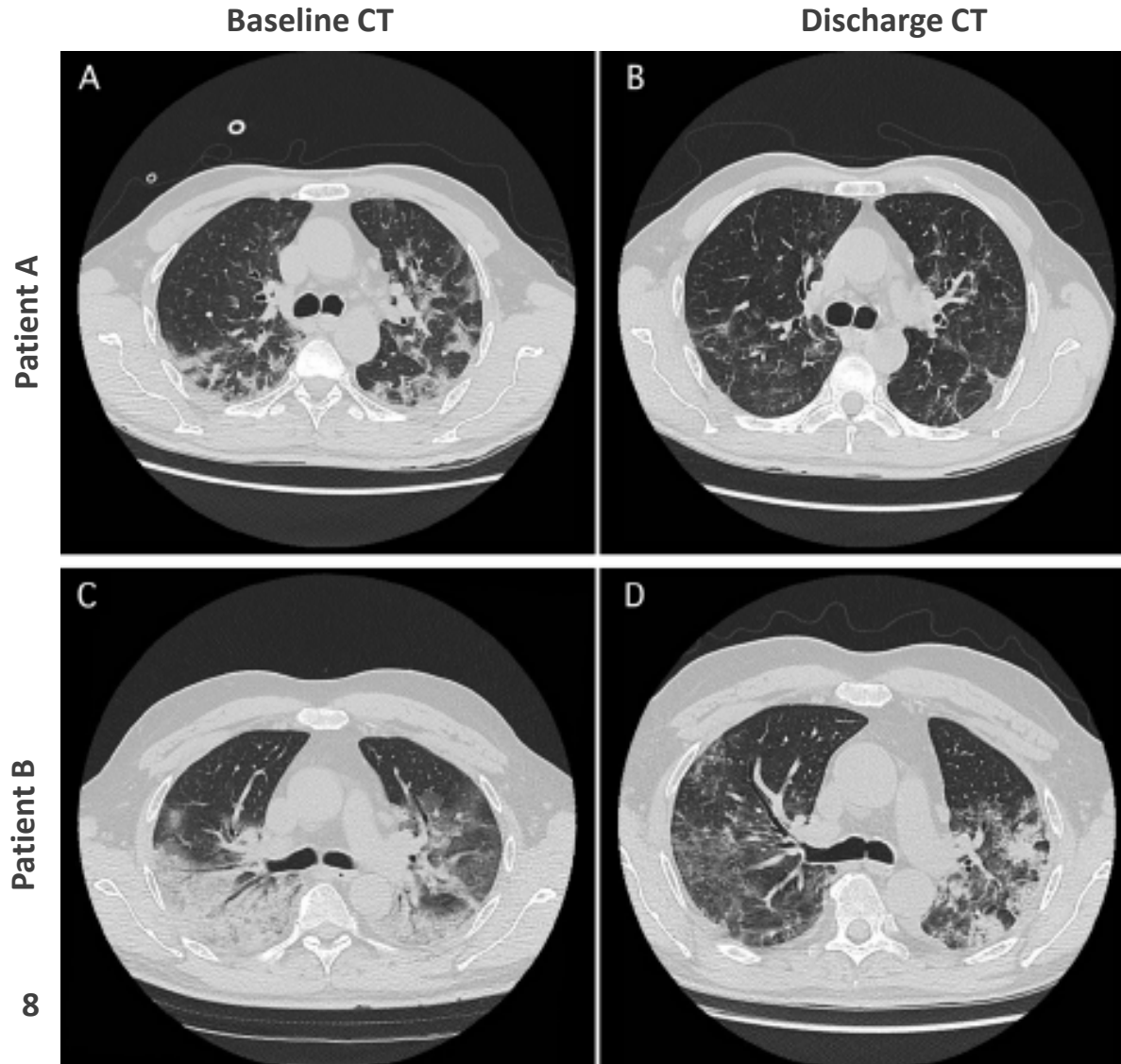


Patients at Risk	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Mavrilimumab	11	11	3	2	2	2	2	2	1	1	1	1	1	1	1
Comparison group	18	18	15	14	13	12	10	9	9	8	7	7	7	7	7

Fever resolved in 91% (n=10/11 febrile patients) of mavrilimumab-treated patients by Day 14, compared to 61% (n=11/18 febrile patients) of control-group patients (p=0.0093)



# Representative mavrilimumab-treated patients showed significant improvement in lung opacification on computerized tomography (CT) scans, consistent with the overall improvement in their clinical status



**Patient A:** 58 year old male.

- At day 0: febrile, receiving O<sub>2</sub> through a facemask; FiO<sub>2</sub> 0.4, PaO<sub>2</sub> 86 mmHg, lactic acid dehydrogenase (LDH) 374 U/L, C-reactive protein (CRP) 100 mg/L.
- At day 7: afebrile, on room air, SpO<sub>2</sub> 98%, LDH normalized, CRP 12.5 mg/L.

**Patient B:** 56 year old male

- At day 0: febrile, receiving high-low O<sub>2</sub> through a facemask with reservoir bag + 12 hours/day of CPAP, PaO<sub>2</sub> 176 mmHg, LDH 944 U/L, CRP 177 mg/L.
- At day 14: afebrile, on room air, SpO<sub>2</sub> 98%, LDH normalized, CRP 28.2 µg/mL (28.2 mg/L).



# Data from U.S. Investigator-Initiated Study of Mavrilimumab in Severe COVID-19 Pneumonia and Hyperinflammation

**The investigator-initiated study was a randomized, double-blind, placebo-controlled study across a consortium of U.S. academic sites designed to evaluate the efficacy and safety of mavrilimumab versus placebo on top of standard of care therapy in patients with severe COVID-19 pneumonia and hyperinflammation.**

- Enrolled 40 patients with severe COVID-19 pneumonia (all patients presented with pneumonia and hypoxia: all patients required supplemental oxygen, 50% of patients required non-invasive ventilation, none required mechanical ventilation at baseline; median PaO<sub>2</sub>/FiO<sub>2</sub> ratio 137) and hyperinflammation (median C-reactive protein 13.1 mg/dL).
- Concomitant medications at baseline included corticosteroids (65% of patients) and remdesivir (75% of patients). Patients were randomized 1:1 to a single intravenous (IV) infusion of mavrilimumab 6mg/kg (n=21) or placebo (n=19) and were followed for at least 60 days.

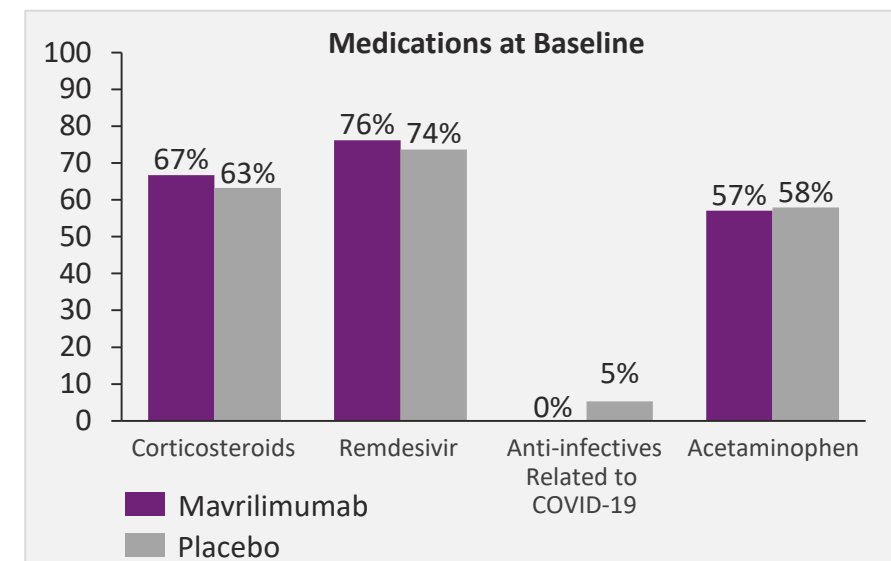
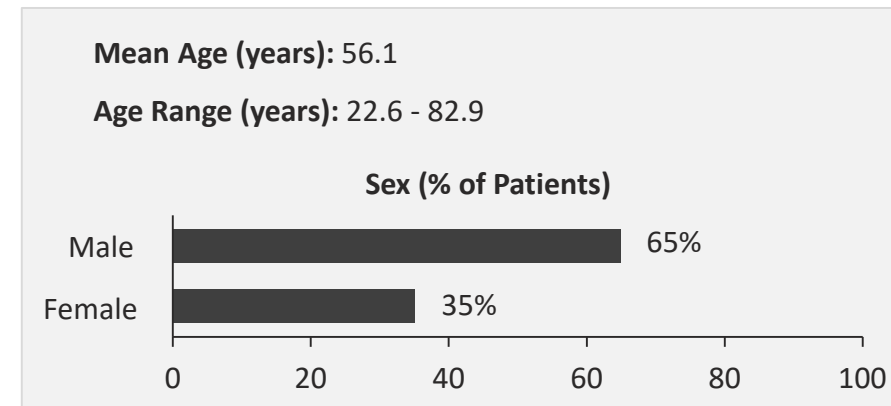
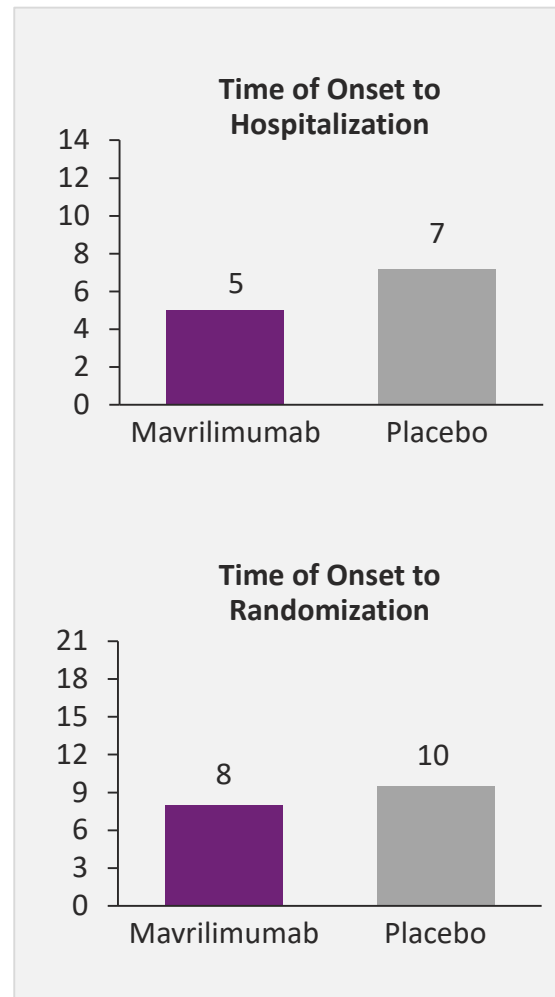
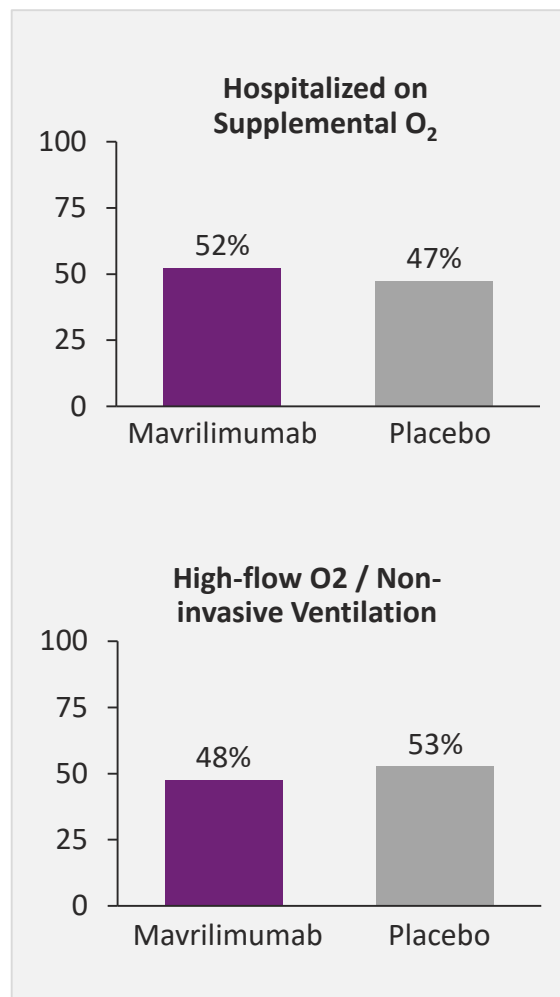
**Data showed an early signal of efficacy, with trends toward clinical improvement as well as lower mortality and shorter duration of mechanical ventilation in patients treated with mavrilimumab on top of corticosteroids, including dexamethasone, and/or remdesivir.**

## **Clinical Outcomes:**

- There was a 20.5% relative increase in the primary efficacy endpoint, the proportion of patients alive and off supplemental oxygen at Day 14 (mavrilimumab: 57.1% [n=21]; placebo: 47.4% [n=19]; nominal p=0.536).
- There was a 20.7% relative increase in the secondary efficacy endpoint, the proportion of patients alive and without respiratory failure<sup>1</sup> at Day 28 (mavrilimumab: 95.2%; placebo: 78.9%; nominal p=0.172).
- There was 1 death (4.8%) in the mavrilimumab arm by Day 28, compared to 3 deaths (15.8%) in the placebo arm (nominal p=0.222). By Day 60 there was 1 death (4.8%) in the mavrilimumab arm, compared to 4 deaths (21.1%) in the placebo arm (nominal p=0.108).
- While the percentage of patients who progressed to mechanical ventilation was similar between treatment arms (mavrilimumab: 23.8% [n=5]; placebo: 21.1% [n=4]), the median (interquartile) duration of mechanical ventilation was shorter in the mavrilimumab arm (12 [9.0, 18.0] days) compared to the placebo arm (17 [11.0, 24.5] days). Additionally, 4 of the 5 patients who progressed to mechanical ventilation in the mavrilimumab arm had recovered by Day 28, whereas all patients in the placebo arm who progressed to mechanical ventilation had died by Day 28.
- There was no difference in serious adverse events between the mavrilimumab arm and the placebo arm.

# Baseline Demographics and Baseline Characteristics

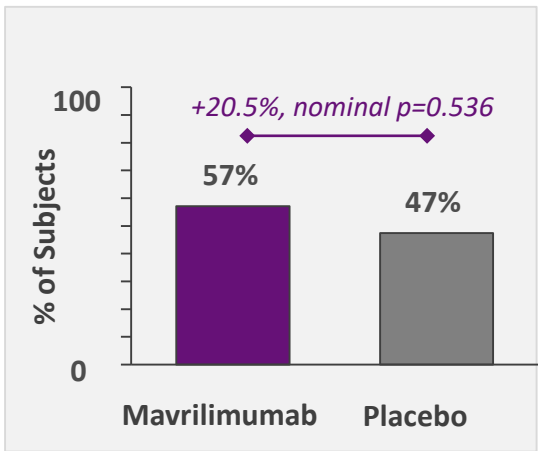
U.S. investigator-initiated study in patients with severe COVID-19 pneumonia and hyperinflammation



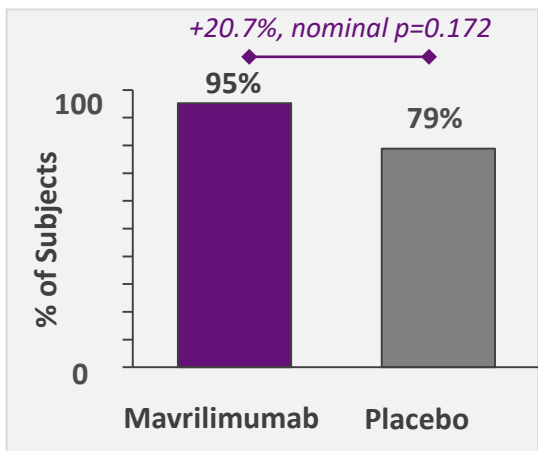
# Encouraging Trends toward Reduced Mortality and Duration of Mechanical Ventilation

U.S. investigator-initiated study in patients with severe COVID-19 pneumonia and hyperinflammation

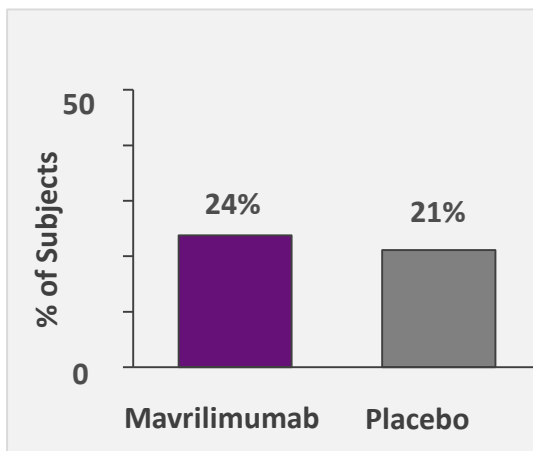
**Primary Endpoint: Proportion of Patients Alive and off Supplemental Oxygen at Day 14**



**Secondary Endpoint: Proportion of Patients Alive and Without Respiratory Failure at Day 28**

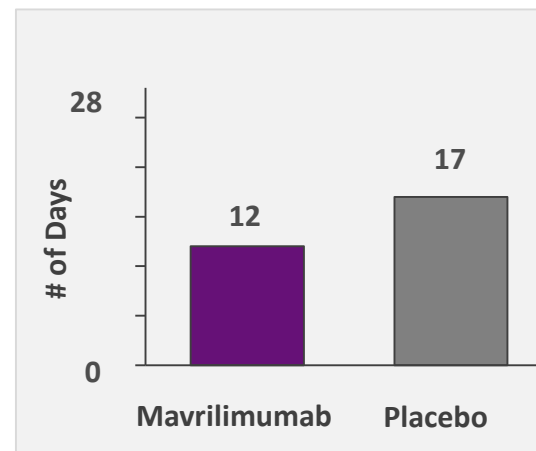


**Percentage of Patients who Progressed to Mechanical Ventilation**



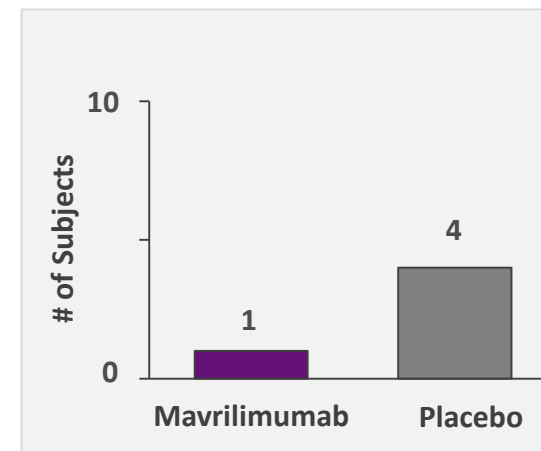
The percentage of patients who progressed to mechanical ventilation was similar between treatment arms (mavrilimumab: 23.8% [n=5]; placebo: 21.1% [n=4]).

**Duration of Mechanical Ventilation**



The median (interquartile) duration of mechanical ventilation was shorter in the mavrilimumab arm (12 [9.0, 18.0] days) compared to the placebo arm (17 [11.0, 24.5] days). 4 of the 5 patients who progressed to mechanical ventilation in the mavrilimumab arm had recovered by Day 28, whereas all patients in the placebo arm who progressed to mechanical ventilation had died by Day 28.

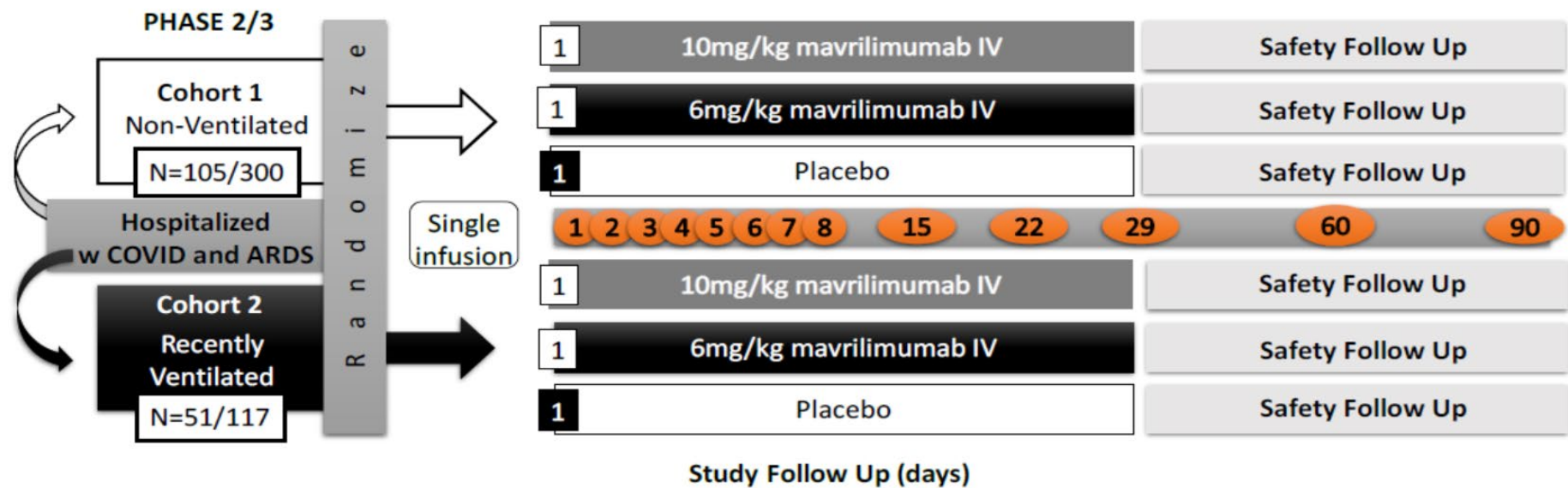
**Death by Day 60**



There was 1 death (4.8%) in the mavrilimumab arm by Day 28, compared to 3 deaths (15.8%) in the placebo arm (nominal  $p=0.222$ ). By Day 60 there was 1 death (4.8%) in the mavrilimumab arm, compared to 4 deaths (21.1%) in the placebo arm (nominal  $p=0.108$ ).

# Phase 2/3 Clinical Trial of Mavrilimumab in Severe COVID-19 Pneumonia and Hyperinflammation

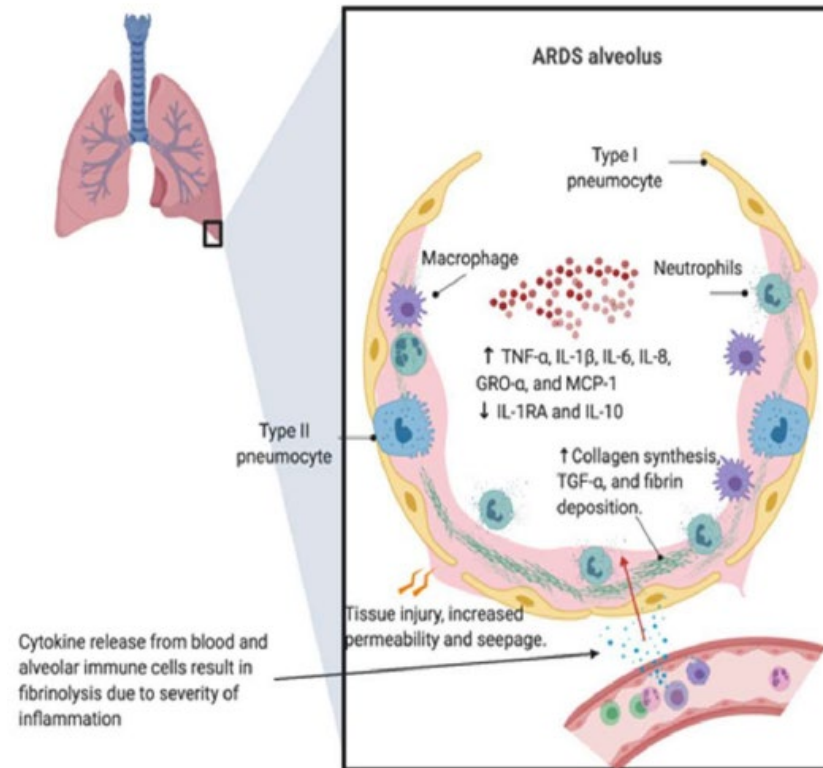
- Key Inclusion Criteria:**
- Positive COVID-19 test within 14 days prior to randomization
  - Hospitalized for COVID-19
  - Bilateral pneumonia on chest x-ray or computed tomography
  - Active fever or recently documented fever within 72 hours prior to randomization
  - Clinical laboratory results indicative of hyper-inflammation
  - Cohort 1: Non-ventilated; requiring supplemental oxygen to maintain oxygen saturation (SpO2) ≥ 92% and not-intubated
  - Cohort 2: Recently ventilated with mechanical ventilation prior to randomization



- Primary Efficacy Endpoints:**
- Cohort 1:
- Proportion of patients alive and free of mechanical ventilation at Day 29.
- Cohort 2:
- Mortality rate at Day 29.

# Viral Infections Causing ARDS (i.e., influenza, H1N1, RSV, COVID-19, etc.) Have an *Inflammatory Pathophysiology*, Primarily Precipitated by Cytokine Storm

- Uncontrolled pro-inflammatory response, originating from the focal infected area, spreading through circulation and manifests as a **multiorgan failure** and **ARDS**
- Inflammation of the alveolar epithelial cells drives development of severe disease, destroying gas exchange and allowing **further viral exposure**
- Approach to treatment is **addressing host response** directly by targeting innate immune pathways that amplify inflammatory signals and contribute to epithelial damage

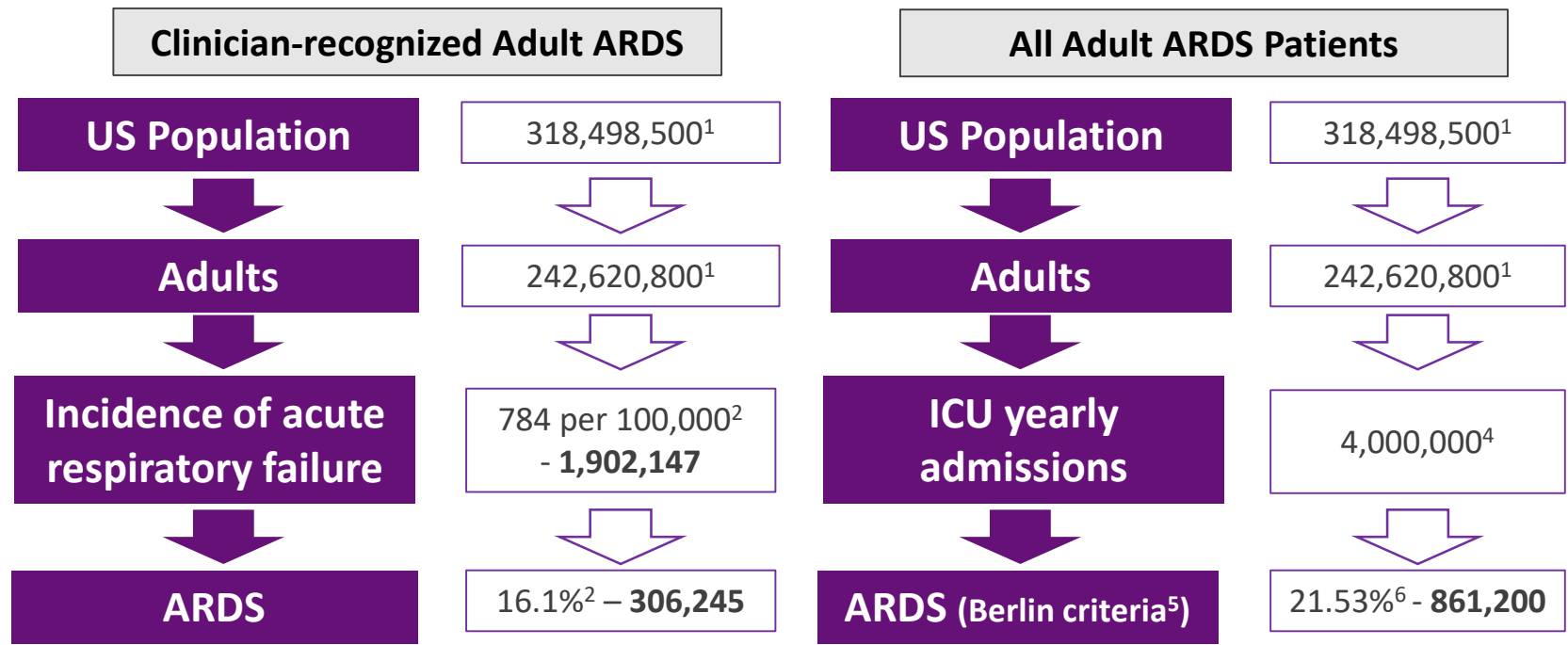


McGonagle, et al., Autoimmunity Reviews (2020), <https://doi.org/10.1016/j.autrev.2020.102537>

## Under-diagnosis of viral infections causing ARDS

- Viral infection is sufficient to cause severe pneumonia and ARDS, but it can also act in conjunction with or be followed by bacterial agents, (most commonly by *S. aureus* and *S. pneumoniae*)
- Clinicians fail to clinically diagnose influenza in **up to two-thirds** of patients with confirmed influenza

# There are between 300k and 860k Cases of Adult ARDS in the U.S. Every Year; Significant Unmet Need Remains in These Populations



- Excludes ARDS associated with COVID-19
- Pediatric ARDS occurs less often
- Most common causes of ARDS are pneumonia (59%) and sepsis (16%)<sup>3</sup>
- 84.5% of ARDS cases require mechanical ventilation<sup>7</sup>
- Considerable mortality (~40%<sup>8</sup>) with no effective treatments outside mechanical ventilation

**~300,000 – 860,000 ARDS Cases Annually in US\***

1) KFF's State Health Facts. Population Distribution by Age [Kaiser Family Foundation estimates based on the Census Bureau's American Community Survey, 2008-2018].  
2) Stefan MS, Shieh MS, Pekow PS, et al. J Hosp Med. 2013;8(2):76–82. doi:10.1002/jhm.2004  
3) Bellani G, Laffey JG, Pham T, et al JAMA. 2016;315(8):788–800. doi:10.1001/jama.2016.0291  
4) Mullins PM, Goyal M, Pines JM. Acad Emerg Med. 2013;20(5):479–486. doi:10.1111/acem.12134  
5) ARDS Definition Task Force. JAMA 2012;307(23):2526-2533.  
6) Laffey JG, Madotto F, Bellani G, et al. Lancet Resp Med. 2017;5(8):627-638  
7) Bellani G, Laffey JG, Pham T, et al Am J Respir Crit Care Med 2017;195(1):67–77  
8) Calfee CS, Delucchi KL, Sinha P, et al. Lancet Respir Med. 2018;6(9):691–698. doi:10.1016/S2213-2600(18)30177-2

*\*There may be different ARDS phenotypes – some of which may not be ideal for GM-CSF inhibition. Further research is needed to understand which patient sub-types would best benefit from treatment with mavrilimumab*



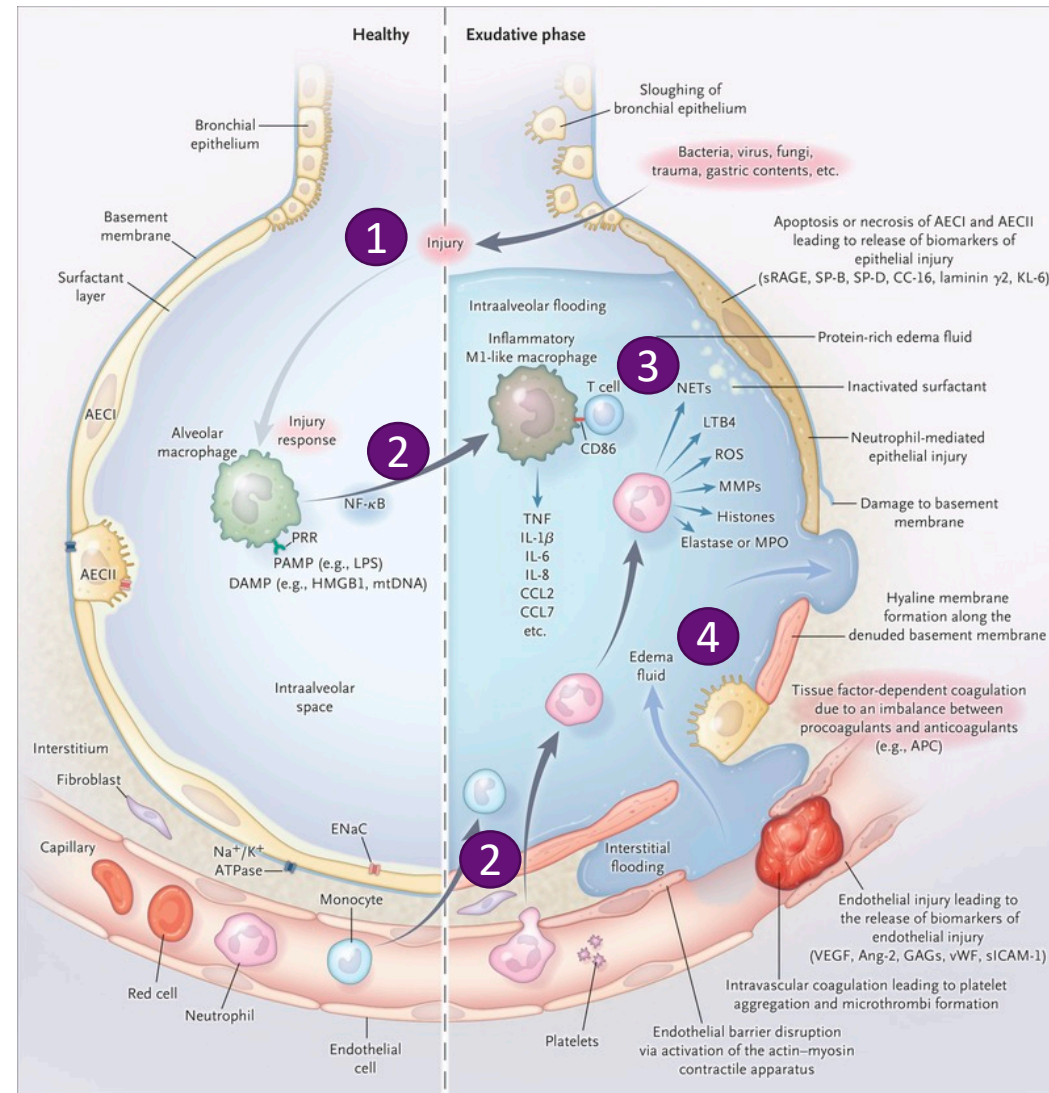


# Cytokine Cascade Amplification System in the Pathophysiology of ARDS

## Pathophysiology of ARDS (Exudative Phase)

- 1 • Inflammatory insults, either locally from the lungs or systemically from extra-pulmonary sites, affect bronchial epithelium, alveolar macrophages, and vascular endothelium

- 4 • Extensive damage to lung epithelia and endothelia results in an impaired alveolar-capillary barrier.  
• Disruption of this barrier allows protein-rich fluid to enter the alveoli causing fluid accumulation in alveolar spaces (pulmonary edema) interfering with gas exchange



- 2 • Resident alveolar macrophages secrete proinflammatory cytokines, leading to **neutrophil** and **monocyte** or **macrophage** recruitment, as well as activation of **alveolar epithelial cells** and **effector T cells**, to promote and sustain inflammation and tissue injury.
- 3 • Hyperactivation of myeloid cells and T-cells produce large amounts of inflammatory cytokines, which in turn lead to **endothelial activation** and microvascular injury ultimately leading to barrier disruption in ARDS which can worsened by mechanical stretch.



# The Role of Mavrilimumab Throughout the Immune System and its Potential to Treat COVID-19 Pneumonia and ARDS More Broadly

Mechanisms driving ARDS pathophysiology	Targetable by Mavrilimumab <sup>(4-14)</sup>	Targetable by anti-IL-6 <sup>(15-20)</sup>	Targetable by anti-IL-1β <sup>(21-26)</sup>
Recruitment of neutrophils	✓	✓	✓
Neutrophil longevity	✓	Conflicting evidence	
Formation of neutrophil extra cellular traps (NET)	✓		
Activation of AM & polarization to M1-like phenotype	✓		
Th1 inflammation <sup>(1-3)</sup>	✓		
Th17 inflammation <sup>(1-3)</sup>	✓	✓	✓

### Evidence of targetable pathways by anti-IL-6

<sup>1</sup>Wu J Microbiol, Immunol and Infection (2020), <sup>2</sup> Xu Lancet Respir Med (2020), <sup>3</sup> Huang Lancet (2020).

### Evidence of targetable pathways by anti-IL-6

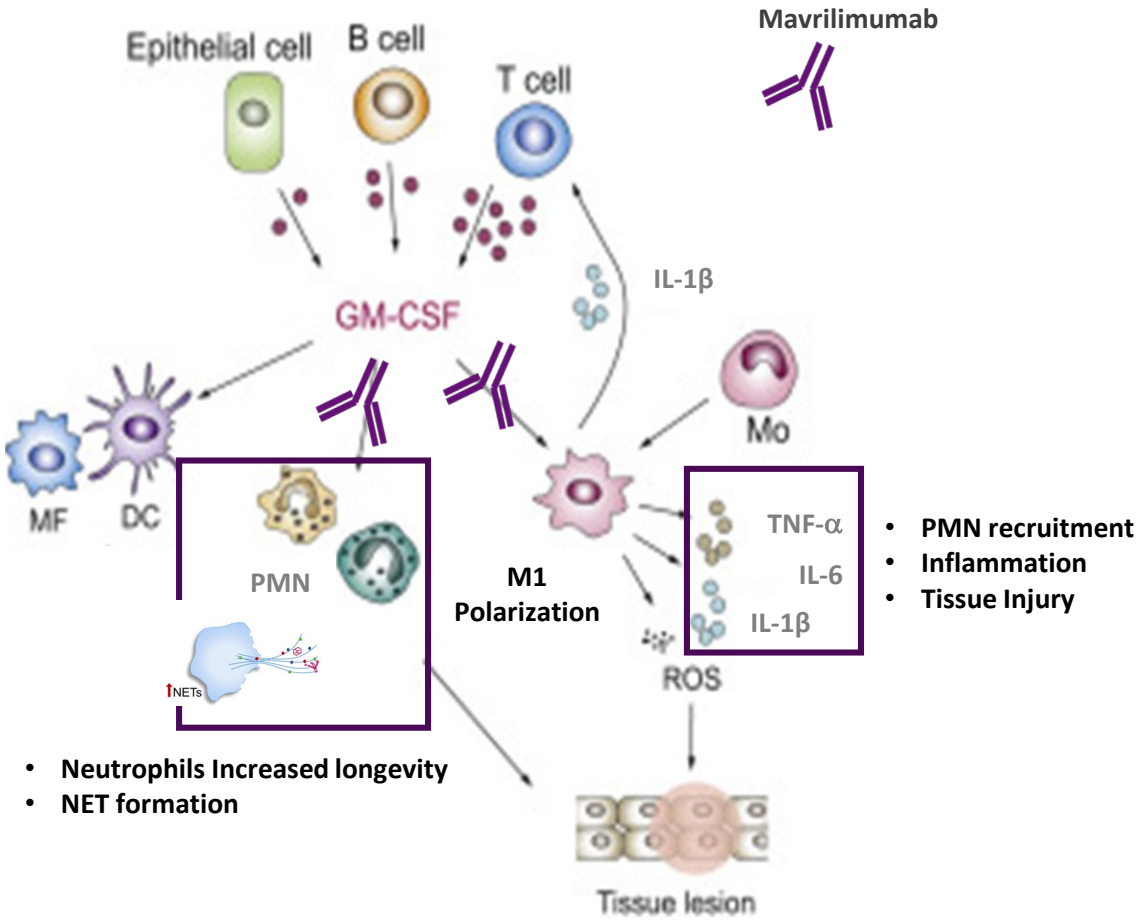
<sup>4</sup> De Alessandris JLB (2019), <sup>5</sup> Matute-Bello Am J Resp Crit Care Med (1997), <sup>6</sup> Juss Am J Resp Crit Care Med 1997 (2016), <sup>7</sup> Yousefi Cell Death and Differentiation (2009), <sup>8</sup> Gray Thorax (2018), <sup>9</sup> Fleetwood JI (2007), <sup>10</sup> Dalrymple BMC Immunol. (2013), <sup>11</sup> Benmerzoug Sci Rep (2018), <sup>12</sup> Krausgruber Nat Imm (2011), <sup>13</sup> Shiomi JI (2014), <sup>14</sup> Shiomi Med Inflamm (2015).

### Evidence of targetable pathways by anti-IL-6

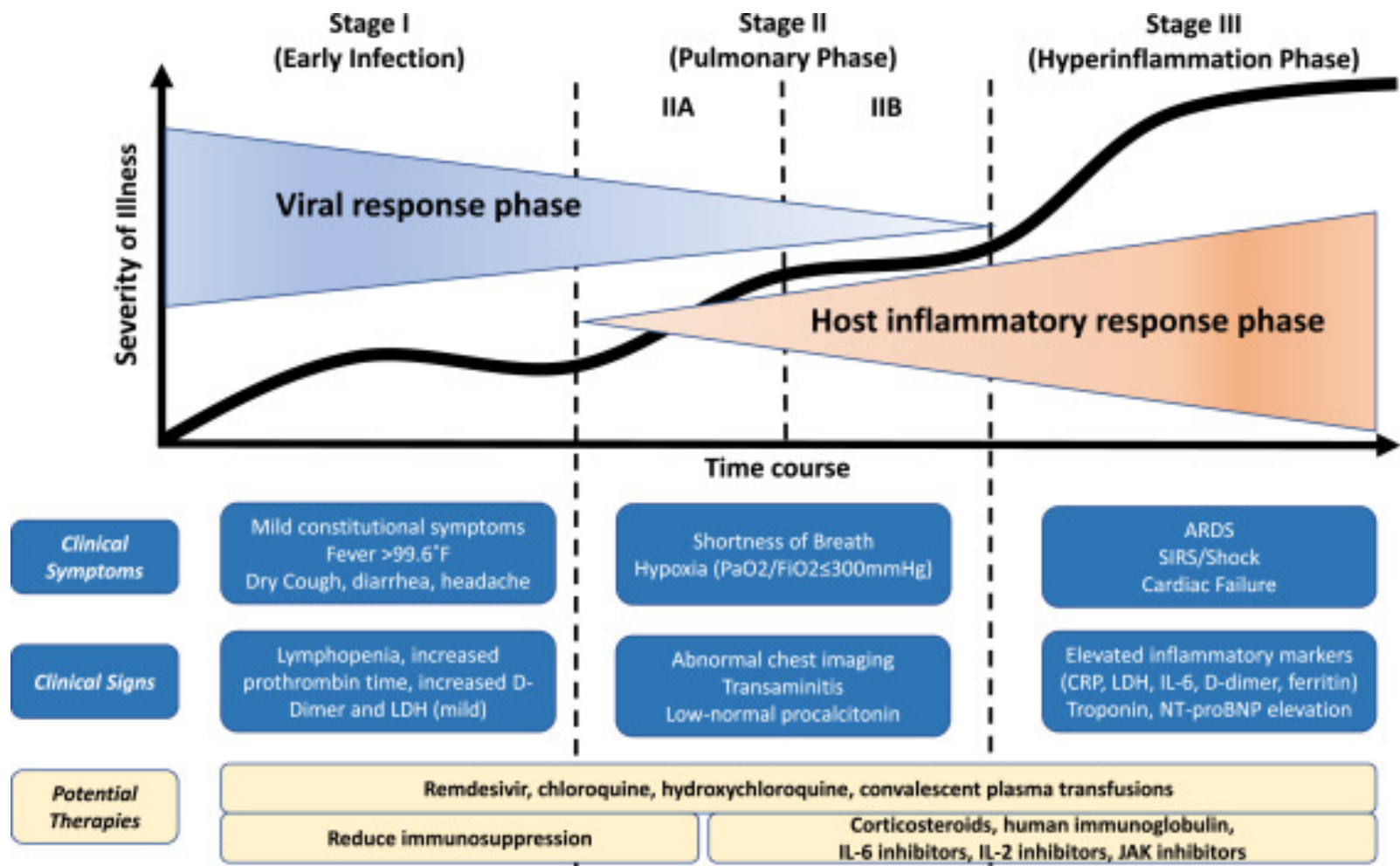
<sup>15</sup> Jones J Infect Dis (2006), <sup>16</sup> Wright Rheumatology (2014), <sup>17</sup> Afford JBC (1992), <sup>18</sup> Biffi JLB (1995), <sup>19</sup> Oh J Exp Med (2011), <sup>20</sup> Yan Sci Rep (2016).

### Evidence of targetable pathways by anti-IL-1β

<sup>21</sup> Sichelstiel PLOS One (2014), <sup>22</sup> Jones AJRCB (2014), <sup>23</sup> Ganter Circ Res (2008), <sup>24</sup> Frank Thorax (2008), <sup>25</sup> Wu JI (2013), <sup>26</sup> Gasse PLOS One (2011).



# Escalating Phases of Disease Progression with COVID-19



Source:  
Hasan K. Siddiqi MD, MSCR , Mandeep R. Mehra MD, MSc , COVID-19 Illness in Native and Immunosuppressed States: A Clinical-Therapeutic Staging Proposal, Journal of Heart and Lung Transplantation (2020), doi: <https://doi.org/10.1016/j.healun.2020.03.012>



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