During the coronavirus disease 2019 (COVID-19) pandemic, concerns have arisen that rationing of life-saving therapies, such as mechanical ventilation or extracorporeal membrane oxygenation (ECMO), could be necessary due to a surge of patients overwhelming available resources and treatment capacities. ECMO support is particularly resource-intensive and should therefore be provided in highly specialized centers, operating formally or informally within a so-called “Hub and Spoke” concept. Consequently, patient transfer capacity between hospitals according to the services needed must be provided to make the most effective use of available resources. Occasionally, patients requiring ECMO support must be transferred after out-of-center initiation of ECMO by a mobile ECMO retrieval team. While this approach has been successfully established in various ECMO centers before the outbreak of the COVID-19 pandemic, data on the feasibility and the results of out-of-center initiation of ECMO during the COVID-19 pandemic are scarce.

We report single-center retrospective data of COVID-19 patients supported with ECMO in our center after out-of-center initiation of ECMO and patient transfer by our ECMO retrieval team. We provide a 24/7 ECMO retrieval service and support during the COVID-19 pandemic.
MOBILE ECMO RETRIEVAL DURING THE COVID-19 PANDEMIC

Our center is located in southwest Germany, bordering France and Switzerland (Figure 1). The geographic conditions result in our hospital serving as a major referral center for regional hospitals in a large area covering an approximately 100 km linear distance radius. Transport times between referring hospitals and our center occasionally exceed 2 hours when airborne transport is not possible.

During the first 12 months of experience with treating COVID-19 patients from March 2020 to the end of February 2021, 37 COVID-19 patients were supported with veno-venous ECMO in our center’s medical intensive care unit (ICU). In 24% of these cases (9/37), ECMO support was initiated by our mobile ECMO retrieval team in the referring hospitals, and patients were transferred on ECMO (Table 1). The ECMO retrieval team reached out to the referring hospitals by land (6/9 [67%]) or by air (3/9 [33%]).

Median age (IQR) of the patients was 61 years (51-65). Criteria for the indication of ECMO were based on previous recommendations (see Table 1 for blood–gas analyses and ventilator settings before initiation of ECMO). Sixty-seven percent of the patients (6/9) were proned prior to ECMO, median duration (IQR) of invasive mechanical ventilation before ECMO was 2 days (1-7). Vascular access was performed by an ultrasound-guided percutaneous approach in Seldinger’s technique, preferentially inserting a double-lumen cannula into the right jugular vein.

Decision for out-of-center initiation of ECMO in contrast to patient transfer prior to cannulation to our center and in-center initiation of ECMO was made by an experienced ECMO physician. When possible, timely transport without ECMO was sought, and only when this was deemed impossible the decision for out-of-center initiation of ECMO was made. During the COVID-19 pandemic, we did not change our criteria for the initiation of ECMO. However, in times of particularly high numbers of patients with COVID-19, we attempted to treat them in the referring hospitals for as long as possible to maintain sufficient capacity in our center for particularly severe cases. For some patients, this may have resulted in the need for out-of-center initiation of ECMO, which might have been prevented by a timely transfer as under prepandemic conditions.

All patients were transferred to our ECMO center by land. Median travel distance (IQR) from the referring hospitals to our center was 66 km (20-92), median regular land travel time (IQR) was 51 minutes (26-92). During the out-of-center missions and patient transfers to our center, the patients experienced no complications and no proven infection of medical personnel with the severe acute respiratory syndrome coronavirus 2 occurred. Personal protective equipment (FFP2 or FFP3 face masks, gowns, and protective goggles) was available and used throughout the mission by all team members and ambulance staff involved. Thirty-three percent of the patients (3/9) survived until hospital discharge. Median duration (IQR) of ECMO was 18 days (2-78) in survivors and 19 days (9-42) in nonsurvivors, respectively. All deceased patients died on ECMO.

In our single-center experience during the COVID-19 pandemic, out-of-center initiation of ECMO was feasible, and patient transfer on ECMO provided by our mobile ECMO retrieval team was safe for all presented patients with COVID-19 and staff. ECMO cannulation in the referring hospitals by the ECMO retrieval team was successful in all
# Table 1: Patient characteristics, treatment, and ventilation data before ECMO implantation

| Patient characteristics | Patient 1 | Patient 2 | Patient 3 | Patient 4 | Patient 5 | Patient 6 | Patient 7 | Patient 8 | Patient 9 |
|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Age (years)             | 59        | 59        | 67        | 39        | 61        | 72        | 62        | 42        | 63        |
| Sex                     | Male      | Female    | Male      | Male      | Female    | Male      | Female    | Male      | Female    |
| BMI (kg/m²)             | 25.2      | 33.9      | 27.8      | 50.9      | 29.4      | 35.2      | 24.8      | 29.4      | 28.6      |
| PMH                     | Burnout   | Breast cancer (CR) | HTN    | HTN    | HTN, DM, CHD | – | DM, infantile brain damage | CHD, bladder cancer |
| ICU survival            | No        | No        | No        | Yes       | Yes       | No        | Yes       | No        | No        |
| Days on ECMO            | 71        | 12        | 32        | 18        | 2         | 14        | 78        | 1         | 24        |
| Vascular access         | Jugular (double lumen cannula) | Jugular (double lumen cannula) | Jugular (double lumen cannula) | Femoro-jugular | Bifemoral | Jugular (double lumen cannula) | Bifemoral | Jugular (double lumen cannula) | Jugular (double lumen cannula) |
| In-hospital treatment before ECMO | | | | | | | | | |
| Duration of in-hospital treatment before ECMO (days) | 6 | 5 | 11 | 4 | 1 | 13 | 6 | 19 | 7 |
| Duration of ICU-treatment before ECMO (days) | 6 | 5 | 8 | 4 | 1 | 10 | 6 | 17 | 5 |
| Duration of invasive mechanical ventilation before ECMO (days) | 2 | 5 | 1 | 3 | 1 | 8 | 0 | 17 | 2 |
| Prognostic positioning  | Yes       | Yes       | No        | Yes       | No        | Yes       | No        | Yes       | Yes       |
| SOFA                    | 9         | 8         | 10        | 14        | 9         | 8         | 7         | 15        | 9         |
| RESP                    | 2         | 3         | 0         | 4         | 4         | 0         | 1         | –4        | –2        |
| PRESERVE                | 3         | 1         | 7         | 1         | 6         | 2         | 4         | 4         | 5         |
| Ventilator settings and arterial blood–gas analyses before ECMO | | | | | | | | | |
| Peak pressure (mbar)    | 30        | 30        | 32        | 32        | 40        | 26        | 30        | 54        | 32        |
| PEEP (mbar)             | 14        | 15        | 18        | 18        | 24        | 16        | 14        | 38        | 18        |
| Dynamic driving pressure (mbar) | 16        | 15        | 14        | 14        | 16        | 10        | 16        | 38        | 18        |
| Tidal volume (mL)       | 450       | 550       | 480       | 500       | 450       | 390       | 382       | 390       | 18        |
| Breathing rate (L/min)  | 24        | 15        | 30        | 22        | 21        | 25        | 15        | 42        | 22        |
| pH                      | 7.3       | 7.4       | 7.1       | 7.2       | 7.4       | 7.2       | 7.5       | 7.1       | 7.2       |
| PaO₂ (mm Hg)            | 56.0      | 46.1      | 78.9      | 75.4      | 51.9      | 91.0      | 48.8      | 60.5      | 83.5      |
| PaCO₂ (mm Hg)           | 68.0      | 42.1      | 67.0      | 62.5      | 42.9      | 71.3      | 26.4      | 74.1      | 80.5      |
| FiO₂                    | 1.0       | 1.0       | 0.9       | 0.9       | 1.0       | 1.0       | 0.85      | 1.0       | 1.0       |

(Continues)
| Patient | PaO₂/FiO₂ (mm Hg) | Laboratory findings before ECMO | Vasopressor support before ECMO | Referring hospital | ECMO retrieval team transfer to referring hospital (by land or by air) | Patient transfer to ECMO referral center (by land or by air) |
|---------|------------------|---------------------------------|---------------------------------|-------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 1       | 56.0             |                                 |                                 | 66                | Land                                                          | Land                                                          |
| 2       | 46.1             |                                 |                                 | 66                | Air                                                           | Land                                                          |
| 3       | 87.7             |                                 |                                 | 70                | Air                                                           | Air                                                           |
| 4       | 83.8             |                                 |                                 | 92                | Air                                                           | Air                                                           |
| 5       | 51.9             |                                 |                                 | 92                | Air                                                           | Air                                                           |
| 6       | 91.0             |                                 |                                 | 41                | Land                                                          | Land                                                          |
| 7       | 57.4             |                                 |                                 | 4                 | Land                                                          | Land                                                          |
| 8       | 60.5             |                                 |                                 | 4                 | Land                                                          | Land                                                          |
| 9       | 83.5             |                                 |                                 | 110               | Land                                                          | Land                                                          |

**TABLE 1 (Continued)**

- **PaO₂/FiO₂ (mm Hg)**
  - Patient 1: 56.0
  - Patient 2: 46.1
  - Patient 3: 87.7
  - Patient 4: 83.8
  - Patient 5: 51.9
  - Patient 6: 91.0
  - Patient 7: 57.4
  - Patient 8: 60.5
  - Patient 9: 83.5

- **Laboratory findings before ECMO**
  - Lactate dehydrogenase (U/L)
    - Patient 1: 326
    - Patient 2: 522
    - Patient 3: 1129
    - Patient 4: 680
    - Patient 5: 535
    - Patient 6: 747
    - Patient 7: 740
    - Patient 8: 1320
    - Patient 9: 846
  - Aspartate aminotransferase (U/L)
    - Patient 1: 79
    - Patient 2: 45
    - Patient 3: 76
    - Patient 4: 278
    - Patient 5: 31
    - Patient 6: 96
    - Patient 7: 36
    - Patient 8: 702
    - Patient 9: 62
  - Alanine aminotransferase (U/L)
    - Patient 1: 36
    - Patient 2: 36
    - Patient 3: 39
    - Patient 4: 138
    - Patient 5: 28
    - Patient 6: 56
    - Patient 7: 22
    - Patient 8: 506
    - Patient 9: 27
  - Creatinine (mg/dL)
    - Patient 1: 1.08
    - Patient 2: 0.65
    - Patient 3: 2.48
    - Patient 4: 7.93
    - Patient 5: 1.50
    - Patient 6: 1.68
    - Patient 7: 0.54
    - Patient 8: 7.66
    - Patient 9: 1.20
  - Troponin T (ng/L)
    - Patient 1: –
    - Patient 2: 260
    - Patient 3: 29
    - Patient 4: 35
    - Patient 5: 70
    - Patient 6: 47
    - Patient 7: 5
    - Patient 8: 296
    - Patient 9: –
  - Troponin I (ng/L)
    - Patient 1: –
    - Patient 2: –
    - Patient 3: –
    - Patient 4: –
    - Patient 5: –
    - Patient 6: –
    - Patient 7: –
    - Patient 8: –
    - Patient 9: 329
  - C-reactive protein (mg/L)
    - Patient 1: 316.8
    - Patient 2: 482.3
    - Patient 3: 502.8
    - Patient 4: 362.4
    - Patient 5: 130.9
    - Patient 6: 394.6
    - Patient 7: 195.2
    - Patient 8: 112.0
    - Patient 9: 61.4
  - Procalcitonin (ng/mL)
    - Patient 1: 0.79
    - Patient 2: 0.73
    - Patient 3: 8.05
    - Patient 4: 8.29
    - Patient 5: 0.47
    - Patient 6: 0.20
    - Patient 7: 0.14
    - Patient 8: 70.90
    - Patient 9: –
  - Interleukin-6 (pg/mL)
    - Patient 1: –
    - Patient 2: 540
    - Patient 3: 3069
    - Patient 4: 714
    - Patient 5: 722
    - Patient 6: 187
    - Patient 7: 860
    - Patient 8: 21
    - Patient 9: –
  - D-dimers (mg/L FEU)
    - Patient 1: –
    - Patient 2: 7.92
    - Patient 3: 4.77
    - Patient 4: 1.38
    - Patient 5: 24.38
    - Patient 6: 9.12
    - Patient 7: 18.12
    - Patient 8: 1.72
    - Patient 9: –

- **Vasopressor support before ECMO**
  - Norepinephrine (µg/kg/min)
    - Patient 1: 0.286
    - Patient 2: 0.222
    - Patient 3: 0.741
    - Patient 4: 0.518
    - Patient 5: 0.118
    - Patient 6: 0.037
    - Patient 7: 0.000
    - Patient 8: 0.556
    - Patient 9: 0.346

- **Referring hospital**
  - Land travel distance to Freiburg University Medical Center (km)
    - Patient 1: 66
    - Patient 2: 66
    - Patient 3: 92
    - Patient 4: 92
    - Patient 5: 35
    - Patient 6: 127
    - Patient 7: 4
    - Patient 8: 4
    - Patient 9: 73
  - Land travel time to Freiburg University Medical Center (minutes)
    - Patient 1: 47
    - Patient 2: 70
    - Patient 3: 92
    - Patient 4: 92
    - Patient 5: 41
    - Patient 6: 110
    - Patient 7: 11
    - Patient 8: 11
    - Patient 9: 51

- **Abbreviations**: BMI, body mass index; CHD, coronary heart disease; CR, clinical remission; DM, diabetes mellitus; ECMO, extracorporeal membrane oxygenation; FiO₂, fraction of inspired oxygen; HTN, arterial hypertension; ICU, intensive care unit; PaCO₂, partial pressure of arterial carbon dioxide; PaO₂, partial pressure of arterial oxygen; PaO₂/FiO₂, ratio of the partial pressure of arterial oxygen to the fraction of inspired oxygen; PEEP, positive end-expiratory pressure; PMH, past medical history; PRESERVE, Predicting Death for Severe ARDS on V-V ECMO; RESP, Respiratory Extracorporeal Membrane Oxygenation Survival Prediction; SOFA, Sequential Organ-Failure Assessment.

*Patient was not on invasive mechanical ventilation before ECMO.*
cases. No major complications occurred during cannulation or patient transfer to our center.

In extraordinary situations, such as during the COVID-19 pandemic, the need for ECMO may increase significantly, and with it the need for out-of-center initiations and transfers of patients on ECMO.\(^1,4\) Considering necessary protective measures for patients and staff, this approach is certainly possible but should ideally be performed by teams and within structures that have been previously established and routinely used under everyday conditions.

**ETHICS APPROVAL AND CONSENT TO PARTICIPATE**

Data collection was approved by the institutional ethics committee of the University of Freiburg (EK 151/14), the need for informed consent was waived.

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**COMPETING INTERESTS**

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**AUTHOR CONTRIBUTIONS**

All authors read and approved the final manuscript.

- **Study design:** Supady
- **Data collection:** Widmeier, Supady, Duerschmied, Benk, Staudacher, Wengenmayer
- **Draft of the manuscript:** Widmeier, Supady

**DATA AVAILABILITY STATEMENT**

All data will be available from the corresponding author on reasonable request.

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