



Sealed (zero gas flow) resistive plate chambers

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Abstract The phase-out of hydro-fluorocarbons, due to their high Global Warming Potential (GWP), affecting the main gas used in Resistive Plate Chambers (RPCs), tetrafluoroethane $C_2H_2F_4$, has increased pressure on existing systems and imposes strong restrictions on its use in new systems. A possible solution to the problem is the substitution of this gas by others with a much lower GWP. Another possibility would be sealed RPCs, i.e., RPCs that do not require a continuous gas flow for their operation. This paper shows the construction structure and test results of a sealed multi-gap RPC operated without gas flow for about 1 year. The results show a stable efficiency of more than 95% and a streamer percentage of less than 1%. The spatial distribution of the hits, the mean charge and the probability of streamers do not reveal significant structures. Similarly, they do not seem to be dependent on operating time.

1 Introduction

Large Resistive Plate Chamber (RPC) systems have their roots in High Energy Physics (HEP) experiments at CERN: ATLAS, CMS, ALICE, where thousands of square meters have been deployed. These devices operate with complex gas systems, equipped with re-circulation and purification units, which require the addition of fresh gas quantities of the order of several $cm^3/min/m^2$ [1], creating logistical, technical and financial problems.

Moreover, the progressive phasing out of hydro-fluorocarbons (HFC), which affects the main gas used on RPCs, Tetrafluoroethane $C_2H_2F_4$, due to high Global Warming Potential (GWP) of 1430, has made the use of these systems even more difficult. This poses problems for existing experiments but, especially for new experiments where current solutions will most likely not be allowed.

A possible solution to the problem is the substitution of this gas by others with a much lower GWP. The community has been involved in this solution as reflected at recent European Committee for Future Accelerators (ECFA) Detector R & D Roadmap symposium of Task Force 1 Gaseous Detectors [2] and in a multitude of published papers such as [3, 4], to name a few. But this solution, for the moment, only applies to $C_2H_2F_4$, apparently there is no substitute for SF_6 , which although not included in the legislation, due to its high GWP of around 23,000, could be included soon. SF_6 is indispensable for timing RPCs, as it allows to operate the detectors at high gas gain to obtain the necessary timing precision [5].

Another possible intermediate solution would be to design RPCs with minimal gas consumption, which would drastically minimize the gas consumption problem. Ultimately, as a final solution, the sealed RPCs (sRPCs), which do not require continuous gas supply (at most sporadically), significantly simplify the gas systems and are a solution that also solves the SF_6 phase-out, if it occurs. This solution would also allow easier use of these devices outside the laboratory [6, 7] or to be installed in remote locations [8, 9] with difficult access or in places where gas systems are not allowed.

A first sRPC prototype with an active area of around $0.10 m^2$ and a single 1 mm gas gap has recently been tested for more than 6 months without appreciable degradation of its performance and without the need to add fresh gas [10]. A second prototype with an area ten times larger and equipped with a multi-gap structure of two 1 mm gas gaps is described in this paper together with the first results about its characterization.

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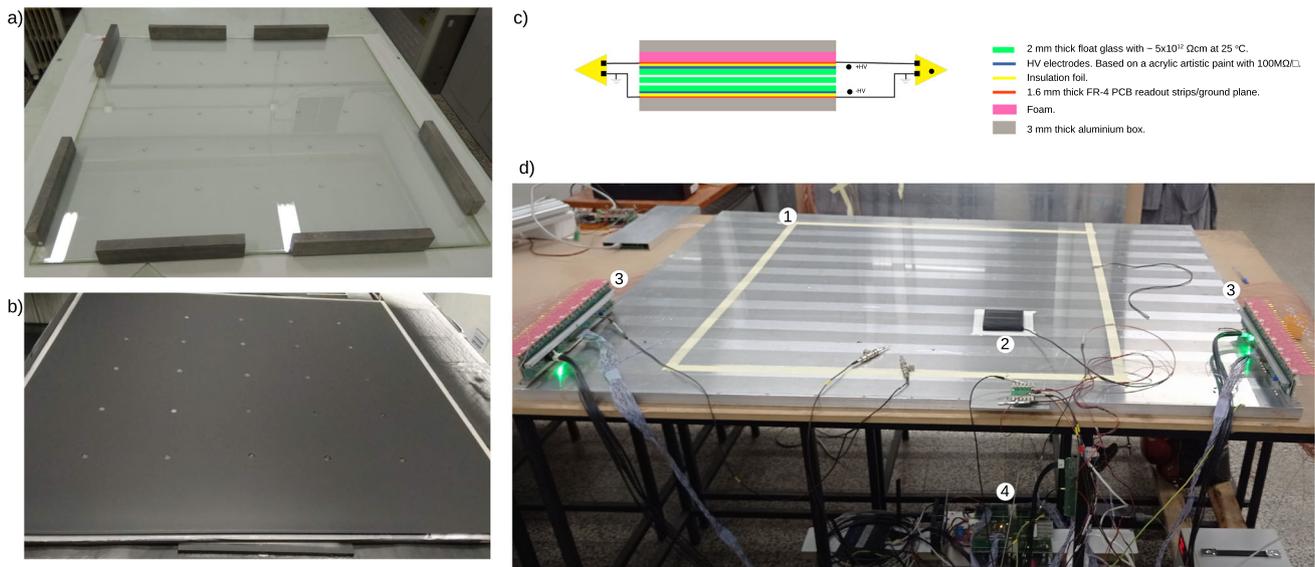


Fig. 1 **a** sRPC module assembly. Stack of glasses during the gluing/sealing process with the weights used to press the structure. The matrix of 5×5 spacers is visible. **b** sRPC module with HV layer already applied. **c** Sketch of the inner structure of the sRPC module and readout. **d** Experimental arrangement showing: 1-aluminum box housing the sRPC module, 2-upper scintillator, the lower scintillator is located immediately below the sRPC aluminum box and is not visible in the photo. 3-FEE used to readout the sRPC module and reference scintillators and 4-DAQ system

2 Experimental setup

2.1 Sealed RPC design

The sRPC module is a multi-gap structure [11] equipped with two gaps defined by three 2 mm thick soda lime glass electrodes¹ of about 1000×1000 mm separated by 1 mm spacers. The module includes a 5×5 spacer matrix made of soda lime glass disks (10 mm diameter and 1 mm thick) in the center of the active area, visible in Fig. 1a, and a row in the periphery. Spacers are glued to the glass electrodes in order to keep the gap uniformity over all active area. The assembly is kept under controlled pressure, and all peripheral surfaces are covered with an epoxy glue guaranteeing sealing and mechanical strength. Gas inlets and outlets (used for gap filling) are made with standard plastic dispensing needles (from LoctiteTM). The HV electrodes are made up of a semi-conductive² layer airbrushed to the outer surface of the outermost glasses, see Fig. 1b. After assembly the gaps are filled with a mixture of 97.5% $C_2H_2F_4$ and 2.5% SF_6 .

2.2 Sealed RPC readout

The experimental setup for the characterization of the sRPC prototype consists of a sRPC module, enclosed in an aluminum box, and a plastic scintillator telescope, composed of two scintillators, one above and one below the sRPC module. These are used as reference counters for the determination of the sRPC response to cosmic-ray muons.

The sRPC module is read out by a readout strip plane³ equipped, in one side, with thirty-two 30 mm width, 31 mm pitch and 1050 mm long copper strips, located on top of the module. A ground plane, placed on bottom completes the readout structure. The complete structure is enclosed in an aluminum box that provides the necessary electromagnetic insulation and mechanical rigidity. A sketch of the inner structure of the module is shown in Fig. 1c. Every strip is connected at each end to a coaxial cable inner conductor, while the outer conductor is connected to the ground plane. The coaxial cables are terminated in MMCX RF connectors.

The scintillator telescope is composed of two parallelepipeds $100 \times 100 \times 10$ mm³ scintillators, placed on top and bottom of the sRPC aluminum box, read out on the smaller face by one Si-PMTs (MICROFC-60035-SMT).

Both the sRPC and the Si-PMTs signals are fed to fast FEE [12] (without amplification stage in the case of Si-PMT readout) borrowed from the HADES RPC-TOF group [13] capable of measuring time and charge in a single channel. The resulting signals are read out by the TRB board [14] equipped with 128 multi-hit TDC (TDC-in-FPGA technology) channels with a time precision better than 20 ps.

With this arrangement we are able to provide information on:

¹ With bulk resistivity of $\approx 5 \times 10^{12} \Omega\text{cm}$ at 25 °C.

² Based on an artistic acrylic paint with around $100 M\Omega/\square$.

³ Made of 1.6 mm Flame Retardant 4 (FR4) Printed Circuit Board (PCB).

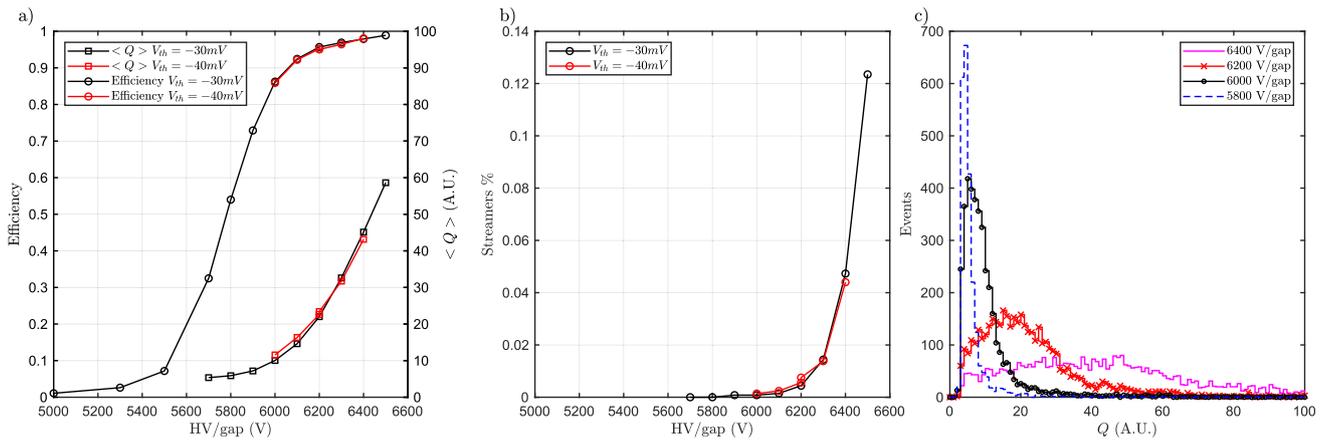


Fig. 2 **a** Efficiency, mean charge and **b** streamer percentage as a function of HV/gap for two different FEE thresholds, V_{th} , -30 mV and -40 mV. The points have been connected by lines to guide the eye. **c** charge spectra from 5800 to 6400 V/gap. The measurement was taken at average room temperature of 20.3 °C and average atmospheric pressure of 1001 mbar

- Charge, Q , as the sum of the induced charge on the strips (or the mean charge, $\langle Q \rangle$, as the mean of Q), and streamer percentage as the percentage of events with a charge higher than 100 (A.U.).
- Time, T , as the half-sum of the times at both ends for the strip with maximum charge.
- Longitudinal position to the strips, Y , as the difference of the times at both ends for the strip with maximum charge multiplied by the propagation velocity on the strip, ≈ 202 mm/ns.
- Transversal position to the strips, X , as the position of the strip with maximum charge. Both, longitudinal and transversal position with a resolution of about 10 mm sigma.
- Efficiency, defined as the inverse of the quotient of the number of events seen by the scintillator telescope divided by the corresponding number of events seen by the sRPC module.

The detector is tested by simply exposing it to the natural flux of cosmic rays. Two types of runs were performed, one with trigger on the scintillator telescope, hereafter referred as muon-trigger run, and one with trigger on all signals generated by the sRPC module, hereafter referred as self-trigger run.

The high voltage (HV) in the module was connected approximately in August 2022 and kept in operation without interruption. Unfortunately, monitoring only started in April 2023. During all this time the module did not receive any gas injection.

Finally, the relevant environmental variables, temperature, pressure and relative humidity, are recorded to study their influence on the response of the sRPC module.

3 Results of sRPC characterization

Figure 2a and b shows sRPC efficiency, mean charge and streamer probability, respectively, as a function of HV/gap for two different FEE thresholds, V_{th} , -30 mV and -40 mV. The points have been connected by lines to guide the eye. Figure 2c shows the charge spectra from 5800 to 6400 V/gap. The measurements were taken at average room temperature of 20.3 °C and average atmospheric pressure of 1001 mbar. Efficiency, with a typical shape one would expect to measure for a standard RPC of these characteristics (operated in continuous gas flow), reaches a plateau (relatively steep) above 90% for voltages above 6100 V. Above this voltage the average charge and the percentage of streamers increase rapidly. The difference in the measured values for the two FEE thresholds is practically negligible. Based on this plot, the selected working voltage for the rest of the measurements was set to 6200 V and $V_{th} = -30$ mV. At this voltage the efficiency, mean charge and streamer probability are 95.7%, 22.0 (A.U.) and 0.5%, respectively.

Figure 3a shows the number of hits as a function of X and Y for a self-trigger run. There are no noticeable structures except for some hot spots (1), which we identify as being the positions of the spacers, and on the peripheral regions (2) that are attributed to noise injected via the HV cable. Figure 3b and c shows the mean charge and streamer percentage as a function of X and Y showing some structures, probably some of them related to the position of the spacers. Figure 3d shows the charge spectra for 6200 V/gap. Figure 3e–h shows the self-trigger rate, HV current together with laboratory temperature (with a visual notable correlation), mean charge and streamer percentage as a function of time for a period of approximately 2 months. The initial structure corresponds to the HV scan performed. After this, the detector shows a very smooth response without any noticeable alteration in the behavior. The two negative peaks, visible on the charge and streamer percentage plots around 11/06, correspond to a gain loss due to a drop in HV due to the automatic current limiting action on the HV power supply, which had this parameter set too low.

Figure 4a shows the number of hits as a function of X and Y for a muon-trigger run revealing the position of the scintillator telescope. Figure 4b and c shows the mean charge and streamer percentage as a function of X and Y . Figure 4d shows the charge

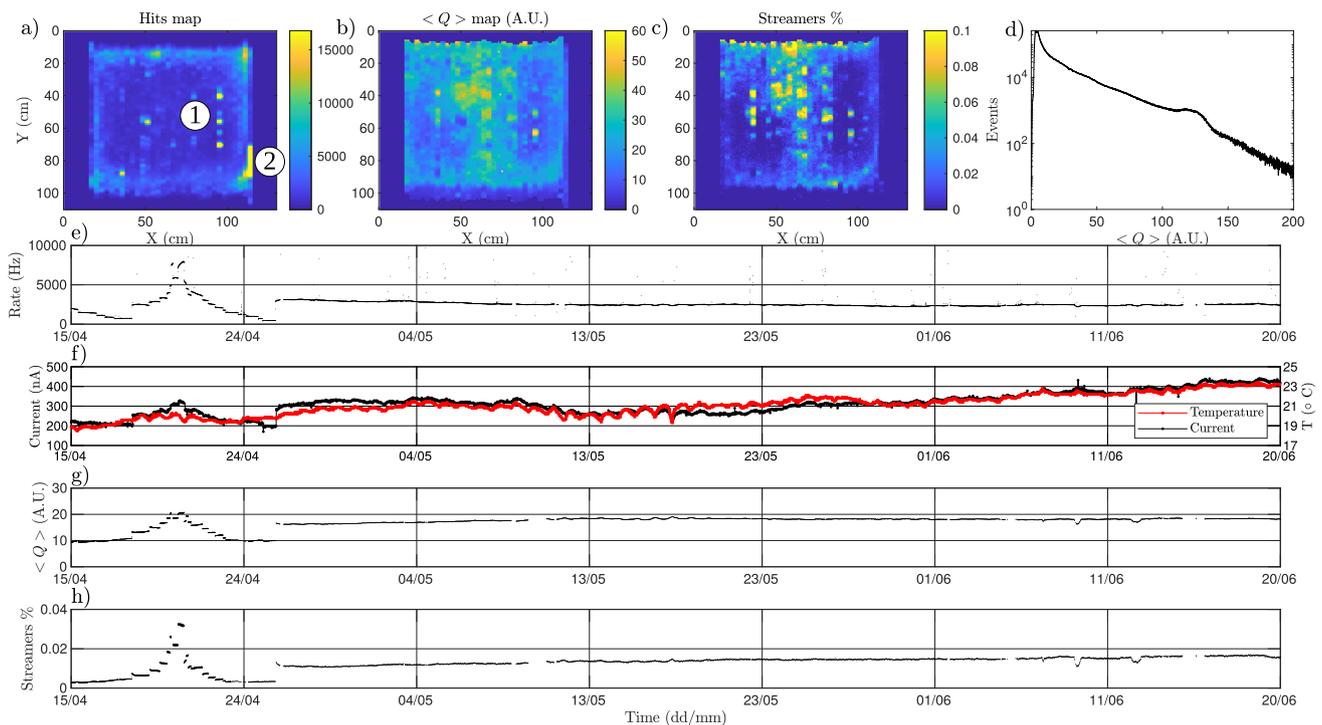


Fig. 3 **a** Hits, **b** mean charge and **c** streamer percentage as a function of XY for a self-trigger run. **d** charge spectra for 6200 V/gap. **e** self-trigger rate, **f** HV current and laboratory temperature **g** mean charge and **h** streamer percentage as a function of time for a period of approximately 2 months

spectra for 6200 V/gap, with a maximum shifted to the right compared to Fig. 3d, as this corresponds to a muon-trigger run where the spectra is dominated by two-gap convolution, while Fig. 3d is dominated by single-gap (dark-counts). Figure 4e and f shows the efficiency and mean charge (the thick line corresponds to the average every four thousand events equivalent to approximately 4 h) without any noticeable structure and stable over time. The average values for efficiency and mean charge are 94.9% and 20.4 (A.U.), respectively. Figure 4g–i shows environmental variables, relative humidity, temperature and atmospheric pressure in the laboratory, which could have an impact on the performance of the sRPC, although at first glance they do not appear to be correlated.

Figure 5 shows the raw correlation of efficiency versus mean charge, atmospheric pressure and temperature in the laboratory for a muon-trigger run. Figure 5a shows a clear correlation, as expected, with mean charge. Figure 5b shows no apparent correlation with atmospheric pressure, also expected, since the volume is sealed and in principle not easily deformable. Finally, Fig. 5c shows a subtle positive correlation with temperature probably due to the decrease in gas density which could be compensated by varying the HV as shown in [15].

The pending measurement to be done is to verify the homogeneity of the detector response as a function of the position within the active area. This is a complicated task with the small reference telescope used here. A telescope with a larger active area than the sRPC and with tracking capability is being installed at the time of submission of this article which will allow to scan the sRPC at once.

4 Conclusions

A sealed RPC module, an RPC requiring no gas flow for its operation, of 1 m² of area constituted by a multi-gap structure with 2 gaps of 1 mm has been operated for approximately 1 year without apparent degradation of the detector main characteristics and without the need for fresh gas addition.

The monitoring results, available from the tenth month of operation, show a performance similar to what could be expected from such a detector operated in a continuous gas flow, efficiency higher than 95% and streamer percentage below 1%. The spatial distribution of self-trigger hits, mean charge and streamer percentage do not reveal significant structures. Similarly, these magnitudes do not seem to depend (for the moment) on operating time (they remain stable over time), with a slight correlation with operating temperature and no correlation with atmospheric pressure.

These results seem to point to the possibility of the operation of large area (> 1 m²) multi-gap RPCs operated for extended periods of time (> 1 year) without fresh gas apportion when exposed (at least) to the natural cosmic-ray flux.

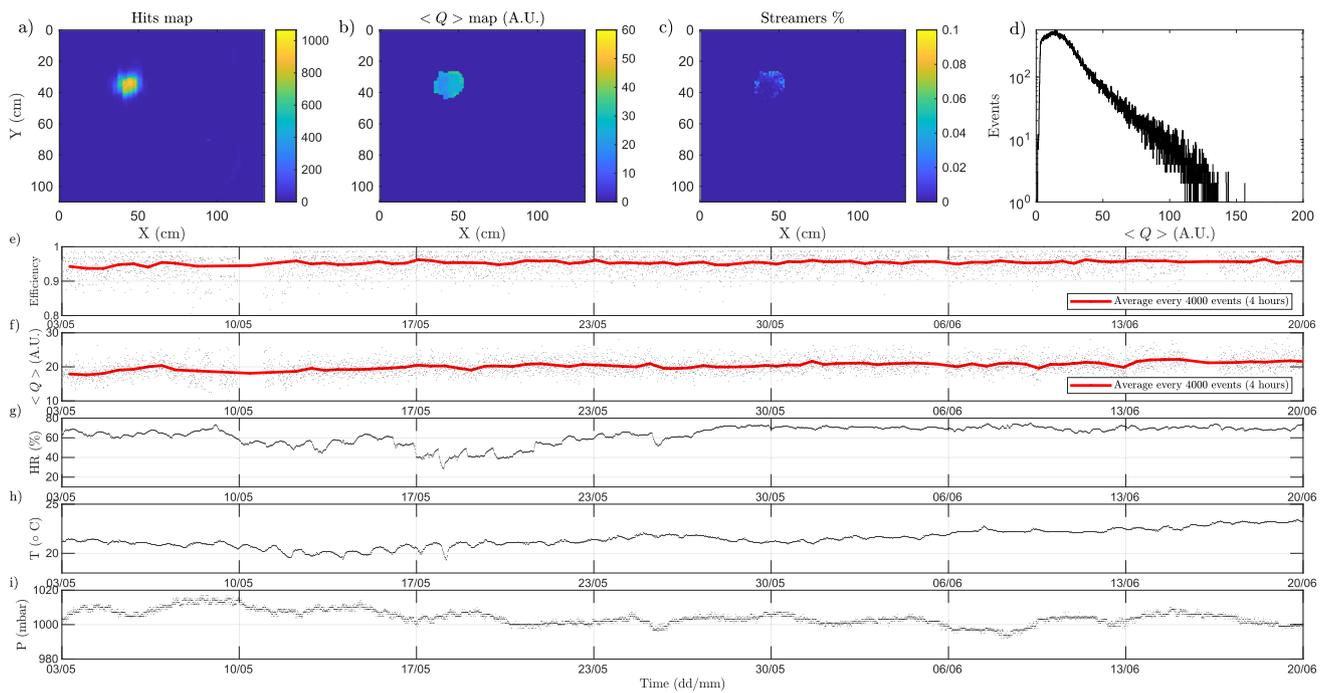


Fig. 4 **a** Hits, **b** mean charge and **c** streamer percentage as a function of XY for a muon-trigger run. **d** charge spectra for 6200 V/gap. **e** efficiency, **f** mean charge, **g** laboratory relative humidity, **h** laboratory temperature and **i** atmospheric pressure as a function of time for a period of slightly less than 2 months

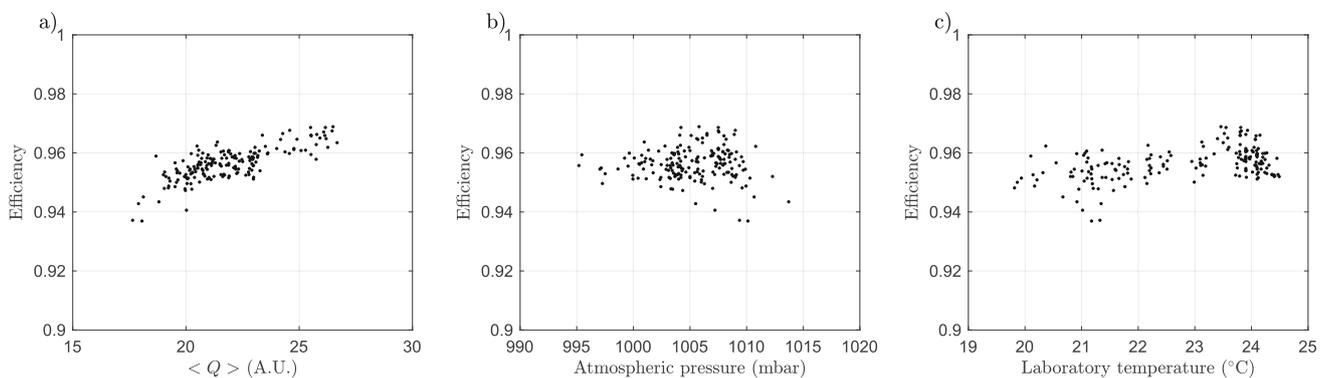


Fig. 5 Raw correlation of efficiency as a function of **a** mean charge, **b** atmospheric pressure and **c** laboratory temperature for a muon-trigger run

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Data Availability Statement This manuscript has associated data in a data repository. [Authors' comment: Data sets generated during the current study are available from the corresponding author on reasonable request].

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