36 Jolley CJ, Luo Y-M, Steier J, Reilly C, Seymour J, Lunt A, Ward K, Rafferty GF, Polkey MI and Moxham J. Neural respiratory drive in healthy subjects and in COPD. Eur Respir J 2009; 33: 289–297. DOI: 10.1183/09031936.00093408

37 Lokin JLC, Dulger S, Glas GJ and Horn J. Transesophageal Versus Surface Electromyography of the Diaphragm in Ventilated Subjects. Respiratory care September 2020 vol 65 no 9. DOI: 10.4187/respcare.07094

38 Sauer J, Grashoff J, Carbon NM, Koch WM, Weber Carstens S and Rostalski P. Automated characterization of patient–ventilator interaction using surface electromyography. Annals of Intensive Care (2024) 14:32 https://doi.org/10.1186/s13613-024-01259-5

39 Scholten AWJ, van Leuteren RW, de Jongh FH, van Kaam AH and Hutten GJ. Simultaneous measurement of diaphragm activity, chest impedance, and ECG using three standard cardiorespiratory monitoring electrodes. Pediatric Pulmonology. 2022;1-9. doi:10.1002/ppul.26096

40 Scholten AWJ, van Leuteren RW, de Jongh FH, van Kaam AH and Hutten GJ. Simultaneous measurement of diaphragm activity, chest impedance, and ECG using three standard cardiorespiratory monitoring electrodes. Pediatric Pulmonology. 2022;57:2754-2762. doi:10.1002/ppul.26096

41 van Leuteren RW, et al. Cardiorespiratory monitoring in the delivery room using transcutaneous electromyography. Arch Dis Child Fetal Neonatal Ed 2021;106:F352–F356. doi:10.1136/archdischild-2020-319535

42 Kraaijenga JV, Hutten GJ, de Jongh FH and van Kaam AH. Transcutaneous Electromyography of the Diaphragm: A Cardio-Respiratory Monitor for Preterm Infants. Pediatric Pulmonology 50:889–895 (2015). DOI 10.1002/ppul.23116

43 Scholten AWJ, Zhan Z, Niemarkt HJ, et al. Cardiorespiratory monitoring with a wireless and nonadhesive belt measuring diaphragm activity in preterm and term infants: a multicenter non-inferiority study. Pediatr Pulmonol. 2023;1-8. doi:10.1002/ppul.26695

44 de Waal G, van Leuteren RW, de Jongh FH, van Kaam AH and Hutten GJ. Patient-ventilator asynchrony in preterm infants on nasal intermittent positive pressure ventilation. Arch Dis Child Fetal Neonatal Ed. 2019 May;104(3):F280-F284. doi: 10.1136/archdischild-2018-315102

45 de Waal CG, Kraaijenga JV, Hutten GJ, de Jongh FH and van Kaam AH. Breath detection by transcutaneous electromyography of the diaphragm and the Graseby capsule in preterm infants. Pediatric Pulmonology 2017 Dec; 52(12): 1578-1582. doi: 10.1002/ppul.23895

46 Hough JL, Shearman AD, Jardine L and Schibler A. Nasal high flow in preterm infants: A dose-finding study. Pediatric Pulmonology 2020 March, 55(3):616-623. doi 10.1002/ppul.24617

47 Williams EE, Hunt KA, Jeyakara J, Subba-Rao R, Dassios T and Greenough A. Electrical activity of the diaphragm following a loading dose of caffeine citrate in ventilated preterm infants. Pediatric Research (2020) 87:740–744; https://doi.org/10.1038/s41390-019-0619-x

48 de Waal CG, Hutten GJ, Kraaijenga JV, de Jongh FH and van Kaam AH. Doxapram Treatment and Diaphragmatic Activity in Preterm Infants. Neonatology. 2019;115(1):85-88. doi: 10.1159/000493359

49 de Waal CG, Hutten GJ, de Jongh FH and van Kaam AH. The Effect of Minimally Invasive Surfactant Therapy on Diaphragmatic Activity. Neonatology 2018;114:76–81. DOI: 10.1159/000487916

50 Maarsingh EJW, Oud M, van Eykern LA, Hoekstra MO and van Aalderen WMC. Electromyographic monitoring of respiratory muscle activity in dyspneic infants and toddlers. Respiratory Physiology & Neurobiology 150 (2006) 191–199. doi:10.1016/j.resp.2005.05.029

51 Koopman AA, van Dijk J, Oppersma E, Blokpoel RGT and Kneyber MCJ. Surface electromyography to quantify neuro-respiratory drive and neuro-mechanical coupling in mechanically ventilated children. Respiratory Research (2023) 24:77. https://doi.org/10.1186/s12931-023-02374-w

52 Scholten AWJ, van Leuteren RW, de Waal CG, de Jongh FH, van Kaam AH and Hutten GJ. Feasibility of wireless cardiorespiratory monitoring with dry electrodes incorporated in a belt in preterm infants. Meas. 43 (2022) 055003. https://doi.org/10.1088/1361-6579/ac69a9

53 Scholten AWJ, van Leuteren RW, de Waal CG, Kraaijenga JV, de Jongh FH, van Kaam AH and Gerard J. Hutten. Diaphragmatic electromyography in infants: an overview of possible clinical applications. 2023, Pediatric Research; https://doi.org/10.1038/s41390-023-02800-1

54 Jonkman AH, Warnaar RSP, Baccinelli W, Carbon NM, D'Cruz RF, Doorduin J, van Doorn JLM, Elshof J, Estrada Petrocelli L, Grashoff J, Heunks LMA, Koopman AA, Langer D, Moore CM, Nunez Silveira JM, Petersen E, Poddighe D, Ramsay M, Rodrigues A, Roesthuis LH, Rossel A, Torres A, Duiverman ML and Oppersma E, Analysis and applications of respiratory surface EMG: report of a round table meeting. Critical Care (2024) 28:2. https://doi.org/10.1186/s13054-023-04779-x

55 Grashoff J, Petersen E, Walterspacher S and Rostalski P. (2022). Model-based Estimation of Inspiratory Effort using Surface EMG. IEEE Transactions on Biomedical Engineering, 70(1), 247 - 258. https://doi.org/10.1109/TBME.2022.3188183

56 Pozzi M, Rezoagli E, Bronco A, Rabboni F, Grasselli G, Foti G and Bellani G (2022) Accessory and Expiratory Muscles Activation During Spontaneous Breathing Trial: A Physiological Study by Surface Electromyography. Front. Med. 9:814219. doi: 10.3389/fmed.2022.814219

57 van Leuteren RW, de Waal CG, de Jongh FH, Bem RA, van Kaam AH and Hutten GJ, Diaphragm Activity Pre and Post Extubation in Ventilated Critically Ill Infants and Children Measured With Transcutaneous Electromyography, Pediatric Critical Care Medicine, November 2021, Volume 22, Number 11. DOI: 10.1097/PCC.0000000000002828

58 Hutten GJ, van Thuijl HF, van Bellegem ACM, van Eykern LA and van Aalderen WMC. A literature review of the methodology of EMG recordings of the diaphragm. Journal of Electromyography and Kinesiology 20 (2010) 185–190. doi:10.1016/j.jelekin.2009.02.008

59 Scholten AWJ, van Leuteren RW, de Jongh FH, van Kaama AH, Markhorst DG and Hutten GJ. Transcutaneous electromyography as a tool to assess recovery of hemidiaphragmatic paresis: A case report. Journal of Neonatal-Perinatal Medicine 16 (2023) 725–729. DOI:10.3233/NPM-230110

60 Sprikkelman AB, van Eykern LA, Lourens MS, Heymans HSA and van Aalderen WM. Respiratory muscle activity in the assessment Of bronchial responsiveness in asthmatic children.1998 J. Appl.Physiol. 84(3): 897–901.

61 O'Brien MJ, van Eykern LA, Bangbang Oetomo D and van Vught HAJ. Transcutaneous respiratory electromyographic monitoring. Critical Care Medicine, Vol.15, No4, 1987.

unlocking the potential of surface electromyography (sEMG) in respiratory care.

Surface electromyography (sEMG) has proven to be a valuable tool in research, offering unique insights and data. Beyond the controlled research environment, sEMG presents exciting opportunities in medical applications, particularly in respiratory care. Demcon macawi respiratory systems has developed the Macawi SERA, a non-invasive sEMG device utilizing electrodes. This brochure highlights scientific publications that demonstrate the added value of non-invasive sEMG in enhancing respiratory care.

A commonly used technique to measure the electrical activity of muscles is Electromyography. Such measurements are often performed with invasive sensors like needles or esophageal catheters containing electrodes. However, non-invasive adhesive sensors, such as skin electrodes, can also be used for these measurements. This method is known as sEMG. The introduction of the NAVA ventilating technique has shifted the way of looking at sEMG, paving the way for more clinical applications.

Aiming to improve clinical outcomes, Demcon macawi has developed the Surface Electromyography Respiratory Assist (Macawi SERA). This device is a continuous, real-time cardiorespiratory sensor that provides various vital sign measurements (heart rate, heart rate variability, respiratory rate, and corresponding waveforms), updated after each breath. It also quantifies the magnitude of diaphragm activation and provides information on the patient's respiratory drive and spontaneous breathing effort.

The Macawi SERA is the technological successor to the Dipha, a 16-channel amplifier previously developed by Macawi. This new design offers enhanced usability with fewer electrodes while maintaining signal quality.
The Macawi SERA has, along with Dipha and other sEMG technology devices, the potential to:

Improve accuracy in apnea classification in preterm infants compared to CI.
Detect patient-ventilator asynchrony.
Help in assessing the response to a spontaneous breathing trial (SBT).
Monitor real-time diaphragmatic responses, making it useful during interventions like surfactant administration or other therapies.

The overview on the next page including Thesis overview presents scientific research showcasing the added value of non-invasive sEMG as an additional tool to improve respiratory care. It distinguishes between the types of sEMG devices used in study protocols and the application areas for different patient groups.

DEMCON | MACAWI RESPIRATORY SYSTEMS

sEMG related Thesis overview

2005 – Maarsingh EJW. The electrical activity of respiratory muscles. An indirect measure to estimate airway reactivity in children with recurrent wheezing.
2008 – Duiverman ML. Severe Chronic Obstructive Pulmonary Disease.
2009 – Hutten GJ. The relative impact of respiratory muscle activity on tidal flow and lung volume in infants.
2017 – Kraaijenga JVS. Diaphragmatic Electromyography Monitoring In Preterm Infants.
2018 – de Waal CG. Transcutaneous electromyography of the diaphragm – Monitoring breathing and the effects of respiratory support in preterm infants.
2021 – Van Leuteren RW. Electromyography Of The Diaphragm In Infants – Where technique becomes practice.
2023 – Scholten AWJ. Cardiorespiratory monitoring based on diaphragm electromyography - Towards wireless and non-adhesive monitoring in newborn infants.
2024 – Blokpoel R. Patient-ventilator interaction in mechanically ventilated children.

SCIENTIFIC RESEARCH OVERVIEW OF sEMG TECHNOLOGY IN RESPIRATORY CARE

Clinical respiratory feasibility of sEMG technology: 4, 15, 34, 53, 54, 58, 61

Patient group	PRETERM/ TERM INFANTS		PEDIATRIC/ADULTS	
Technical sEMG device	Macawi Dipha	Other	Macawi Dipha	Other
Generic information SEMG technology in respiratory care				
Clinical respiratory feasibility of sEMG technology	40, 41, 51	43	16	17, 19
Correlation studies sEMG to p/flow/CI/GC/NAVA	42	45	37	33, 55
Electrode positioning	12			
Monitoring applications				
Cardiorespiratory monitoring	2, 35, 40	1, 39, 52		
Work of Breathing	13, 14	46		
Therapy effects*	8, 9, 47, 48, 49			21
Weaning of respiratory support	5, 6, 7	57		56
Patient Ventilator Asynchrony	44		29, 30, 32	31, 38
Diagnostics of Hemidiaphragmatic paresis	3	59		
Diagnostics of Asthma			18	20, 24, 50, 60
Diagnostics of Apnea	10		27	
Diagnostics of Cystic fibrosis				22
Diagnostics of Dyspnea				23
Diagnostics of COPD				25, 26, 28, 36
Diagnostics of Chronic Lung Disease (CLD)		11		

* Caffeine, Oxygen, Histamine, Doxapram, Surfactant

REFERENCES

1 Hutten GJ, van Eykern LA, Latzin P, Kyburz M, van Aalderen WM and Frey U. Relative Impact of Respiratory Muscle Activity on Tidal Flow and End Expiratory Volume in Healthy Neonates. Pediatric Pulmonology 43. 882–891 (2008). DOI 10.1002/ppul.20874

2 Kraaijenga JV, Hutten GJ, de Jongh FH and van Kaam AH. Transcutaneous Electromyography of the Diaphragm: A Cardio-Respiratory Monitor for Preterm Infants. Pediatric Pulmonology 50:889–895 (2015).

3 Kraaijenga JV, Hutten GJ, de Jongh FH and van Kaam AH. Diagnosis of Hemidiaphragmatic Paresis in a Preterm Infant with Transcutaneous Electromyography: A Case Report. Neonatology 2015;108:38–41. DOI: 10.1159/000381207

4 van Leuteren RW, Hutten GJ, de Waal CG, Dixon P, van Kaam AH and de Jongh FH. Processing transcutaneous electromyography measurements of respiratory muscles, a review of analysis techniques. Journal of Electromyography and Kinesiology 48 (2019) 176–186. https://doi.org/10.1016/j.jelekin.2019.07.014

5 Kraaijenga JV, de Waal CG, Hutten GJ, et al. Diaphragmatic activity during weaning from respiratory support in preterm infants. Neonatal Ed Published Online First: October 31,2016. doi:10.1136/archdischild-2016-311440

6 Hunt KA, Hunt I, Ali K, Dassios T and Greenough A. Prediction of extubation success using the diaphragmatic electromyograph results in ventilated neonates. J. Perinat. Med. 2020; 48(6): 609–614. https://doi.org/10.1515/jpm-2020-0129

7 Williams EE, Arattu Thodika FMS, Chappelow I, Chapman-Hatchett N, Dassios T and Greenough A. Diaphragmatic electromyography during a spontaneous breathing trial to predict extubation failure in preterm infants. 2022. Pediatric Research; https://doi.org/10.1038/s41390-022-02085-w

8 Kraaijenga JV, Hutten GJ, de Jongh FH, van Kaam AH. The Effect of Caffeine on Diaphragmatic Activity and Tidal Volume in Preterm Infants. J Pediatr 2015;167:70. http://dx.doi.org/10.1016/j.jpeds.2015.04.040

9 van Leuteren RW, Scholten AWJ, Dekker J, Martherus T, de Jongh FH, van Kaam AH, te Pas AB and van Hutten GJ (2021) The Effect of Initial Oxygen Exposure on Diaphragm Activity in Preterm Infants at Birth. Front. Pediatr. 9:640491. doi: 10.3389/fped.2021.640491

10 Kraaijenga JV, Hutten GJ, de Waal CG, de Jongh FH, Onland W and van Kaam AH. Classifying Apnea of Prematurity by Transcutaneous Electromyography of the Diaphragm. Neonatology 2018;113:140–145. DOI: 10.1159/000484081

11 Hutten GJ, van Eykern LA, Latzin P, Thamrin C, van Aalderen WM and Frey U. Respiratory Muscle Activity Related to Flow and Lung Volume in Preterm Infants Compared With Term Infants. Pediatr Res 68: 339–343, 2010

12 van Leuteren RW, Bekhuis RE, de Waal CG, de Jongh FH, van Kaam AH and Hutten GJ. Diaphragmatic electromyography in preterm infants: The influence of electrode positioning. Pediatric Pulmonology. 2019;1–6. https://doi.org/10.1002/ppul.24585

13 van Leuteren RW, de Waal CG, Hutten GJ, de Jongh FH and van Kaam AH. Transcutaneous monitoring of diaphragm activity as a measure of work of breathing in preterm infants. Pediatric Pulmonology. 2021;56:1593–1600. https://doi.org/10.1002/ppul.25284

14 Jeffreys E, Hunt KA, Dassios T and Greenough A. Diaphragm electromyography results at different high flow nasal cannula flow rates. European Journal of Pediatrics (2019) 178:1237–1242. https://doi.org/10.1007/s00431-019-03401-z

15 AbuNurah HY, Russell DW and Lowman JD. The validity of surface EMG of extra-diaphragmatic muscles in assessing respiratory responses during mechanical ventilation: A systematic review. Pulmonology. 2020 ; 26(6): 378–385. doi:10.1016/j.pulmoe.2020.02.008.

16 Bellani G, Bronco A, Arrigoni Marocco S, Pozzi M, Sala V, Eronia N, Villa G, Foti G, Tagliabue G, Eger M and Pesenti A. Measurement of Diaphragmatic Electrical Activity by Surface Electromyography in Intubated Subjects and Its Relationship With Inspiratory Effort. Respir Care 2018;63(11):1341–1349. DOI: 10.4187/respcare.06176

17 Maarsingh EJW, van Eykern LA, Sprikkelman AB, Hoekstra MO and van Aalderen WMC. Respiratory muscle activity measured with a noninvasive EMG technique: technical aspects and reproducibility. J Appl Physiol 88: 1955–1961, 2000.

18 Keijzer PB, van der Kamp MR, Thio BJ, et al. Assessing paediatric exercise-induce bronchoconstriction using electromyography. ERJ Open Res 2020; 6: 00298-2019 [https://doi.org/10.1183/23120541.00298-2019].

19 Sommers J, van den Boorn M, Engelbert RHH, Nollet F, van der Schaaf M and Horn J. Feasibility of muscle activity assessment with surface electromyography during bed cycling exercise in intensive care unit patients. Muscle Nerve 58:688–693, 2018. DOI 10.1002/mus.26330

20 Maarsingh EJW et al. Airflow limitation in asthmatic children assessed with a noninvasive EMG technique. Respiratory Physiology & Neurobiology 133 (2002) 89 /97

21 Maarsingh EJW, van Eykern LA, Sprikkelman AB and van Aalderen WMC. Histamine induced airway response in pre-school children assessed by a non-invasive EMG technique. Respiratory Medicine (2004) 98, 363–372. doi:10.1016/j.rmed.2003.10.014

22 Reilly CC, Ward K, Jolley CJ, Lunt AC, Steier J, Elston C, Polkey MI, Rafferty GF and Moxham J. Neural respiratory drive, pulmonary mechanics and breathlessness in patients with cystic fibrosis. Thorax 2011;66:240e246. doi:10.1136/thx.2010.142646

23 Schmidt M, Kindler F, Gottfried SB, Raux M, Hug F, Similowski T and Demoule A. Dyspnea and surface inspiratory electromyograms in mechanically ventilated patients. Intensive Care Med (2013) 39:1368–1376. doi: 10.1007/s00134-013-2910-3

24 Steier J, Jolley CJ, I Polkey MI and Moxham J. Nocturnal asthma monitoring by chest wall electromyography. Thorax 2011;66:609e614. doi:10.1136/thx.2010.152462

25 Duiverman ML, van Eykern LA, Vennik PW, Koëter GH, Maarsingh EJW and Peter J. Wijkstra PJ. Reproducibility and responsiveness of a noninvasive EMG technique of the respiratory muscles in COPD patients and in healthy subjects. Journal of Applied Physiology 96:1723-1729, 2004. First published Dec 5, 2003; doi:10.1152/japplphysiol.00914.2003

26 Duiverman ML, de Boer EWJ, van Eykern LA, de Greef MHG, Jansen DH, Wempe JB, Kerstjens HAM and Wijkstraa PJ. Respiratory muscle activity and dyspnea during exercise in chronic obstructive pulmonary disease. Respiratory Physiology & Neurobiology 167 (2009) 195–200. doi:10.1016/j.resp.2009.04.018

27 Meijer PM, Oudman KWE, van der Leest S, Wempe JB, Coster JE, Wijkstra PJ and Duiverman ML. Nasal high flow therapy in heart failure patients with central sleep apnea: a report of disproportional occurrence of cardiac arrhythmias. Sleep Medicine 79 (2021) 119e121 https://doi.org/10.1016/j.sleep.2021.01.002

28 Murphy PB, Kumar A, Reilly C, Jolley C, Walterspacher S, Fedele F, Hopkinson NS, William, Man W D-C, Polkey MI, Moxham J and Hart N. Neural respiratory drive as a physiological biomarker to monitor change during acute exacerbations of COPD. Thorax 2011;66:602e608. doi:10.1136/thx.2010.151332

29 Duiverman ML, Huberts AS, van Eykern LA, Bladder G and Wijkstra PJ. Respiratory muscle activity and patient–ventilator asynchrony during different settings of noninvasive ventilation in stable hypercapnic COPD: does high inspiratory pressure lead to respiratory muscle unloading? International Journal of COPD 2017:12 243–257. http://dx.doi.org/10.2147/COPD.S119959

30 Sarlabous L, Estrada L, Cerezo-Hernández A, v. d. Leest S, Torres A, Jané R, Duiverman M and Garde A. Electromyography-Based Respiratory Onset Detection in COPD Patients on Non-Invasive Mechanical Ventilation. Entropy 2019, 21, 258; doi:10.3390/e21030258

31 Ramsay M, Mandal S, Suh E-S, et al. Parasternal electromyography to determine the relationship between patient-ventilator asynchrony and nocturnal gas exchange during home mechanical ventilation set-up. Thorax 2015;70:946–952. doi:10.1136/thoraxjnl-2015-206944

32 Koopman AA, Blokpoel RGT, van Eykern LA, de Jongh FHC, Burgerhof JGM and Kneyber MCJ. Transcutaneous electromyographic respiratory muscle recordings to quantify patient–ventilator interaction in mechanically ventilated children, Intensive Care (2018) 8:12. https://doi.org/10.1186/s13613-018-0359-9

33 Lin L, Guan L, Wu W and Chen R. Correlation of surface respiratory electromyography with esophageal diaphragm electromyography. Respiratory Physiology & Neurobiology 259 (2019) 45–52 https://doi.org/10.1016/j.resp.2018.07.004

34 Grashoff J, Petersen E, Farquharson F, Kustermann M, Kabitz H-J, Rostalski and Walterspacher S. Surface EMG based quantification of inspiratory effort: a quantitative comparison with Pes. Critical Care (2021) 25:441. https://doi.org/10.1186/s13054-021-03833-w

35 de Waal CG, Hutten GJ, Kraaijenga JV, de Jongh FH and van Kaam AH. Electrical activity of the diaphragm during nCPAP and high flow nasal cannula. Arch Dis Child Fetal Neonatal Ed 2017;0:F1–F5. doi:10.1136/archdischild-2016-312300