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Ventilator autotriggering

An underestimated phenomenon in the determination of brain death

The verification of apnea plays a key role in the clinical declaration of brain death but ventilator autotriggering can mimic an intrinsic respiratory drive where there is none. This phenomenon becomes relevant for the management of intensive care patients with severe cerebral injuries who have the potential of progressing to brain death and may delay or even prevent the diagnosis of brain death. It should be a consistent notable aspect in the national guidelines, especially against the background of the increasing gap between the demand and availability of donor organs.

Diagnosing brain death (in Germany denoted as irreversible brain function failure) is one of the most serious multidisciplinary challenges for intensive care staff. Despite the consensus on the general concept of brain death, there are differences in the national guidelines for its determination, which can be explained by the historical development of the guidelines and recommendations and compliance with country-specific characteristics (e. g., different medico-legal requirements). The differences include the number of physicians required, the degree of experience and academic rank of the physicians, the observation time, the clinical premises, the assessment and the order for confirmatory tests (mandatory vs. optional), the impact of therapeutic hypothermia and therapeutic medication of central

nervous system depressing drugs [5, 11, 12, 23, 24, 26, 28]. Moreover, there is also no consistency in the procedure for determining apnea [5, 12, 24]. Objectification of the loss of spontaneous respiration indicates that the medulla, the most rudimentary part of the brain, is damaged and implies that other vital functions requiring control by the central nervous system are also damaged. Therefore, apnea and its testing play a key role in the clinical declaration of brain death and are considered a *conditio sine qua non* [18]; however, differences in the testing for apnea exist for the pre-oxygenation period, predefined partial pressure of carbon dioxide (PaCO₂) levels, the O₂-insufflation mode, the observation period, and clinical objectification [12].

The potential occurrence of ventilator autotriggering (VAT) is a further cause for inconsistency in the determination of apnea in the national guidelines. A VAT is defined as a ventilator being triggered in the absence of patient effort, intrinsic respiratory drive or inspiratory muscle activity [2]. The various synonyms for VAT are listed under the search terms in the Methods section of this article. This phenomenon, which is primarily observed with ventilators of newer generations [30], can lead to confusion among intensive care unit (ICU) staff, resulting in a time delay or even the cancellation of the process of brain death diagnosis.

Methods

The national recommendations and guidelines for the diagnosis of brain death of 15 selected European countries (including all 8 Eurotransplant member states) were evaluated by 2 authors with respect to VAT. Additionally, PubMed and Google Scholar were searched for articles on this topic. The search and evaluation included the terms “brain (stem) death”, “cerebral death” combined with “ventilator(y) autotriggering”, “ventilator autocycling”, “respirator autocycling”, “ventilator selfcycling”, “patient-ventilator asynchrony”, “cardiogenic autotriggering”, “cardiogenic ventilator triggering” as well as the term “cardiogenic respiratory oscillations” and analogous content-related wording describing the same phenomenon. The translations of the official recommendations were checked by 7 native speakers and linguistic experts and one additional researcher double checked the search results and made the final decision.

Results

The search for VAT in the official national recommendations and guidelines of the selected European countries showed variability in various aspects (▣ Table 1).

The phenomenon of VAT is addressed in 3 of the recommendations and guidelines of the 15 selected European countries (Germany, Ireland and Switzerland). In one of these 3 recommendations and guidelines the synonym

Table 1 National guidelines and recommendations for determination of brain death of 15 European countries in the context of ventilator autotriggering (VAT)

Country (year)	Information on potential occurrence of VAT	Comments on etiology/diagnosis/management of VAT
Austria ^{a,q} (2013)	No	None
Belgium ^{b,q} (1987, 2012)	No	None
Croatia ^{c,q} (2004)	No	None
France ^{d,r} (2004)	No	None
Germany ^{e,q} (2015)	Yes	"The loss of respiratory drive has to be evaluated with certainty in case of doubt by disconnection of the patient from the respirator because apnea programs or the triggering of the respirator may erroneously suggest a respiratory drive by pulse-synchronous air flow within the tube."
Hungary ^{f,q} (1998)	No	None
Ireland ^g (2010)	Yes	"Disconnecting the patient from the ventilator removes the chance of artefactual detection of breathing by the ventilator due to the cardiac impulse."
Italy ^{h,r} (2008)	No	None
Luxemburg ^{i,q} (2008)	No	None
Netherlands ^{j,k,q} (2006, 2015)	No	None
Portugal ^l (1998)	No	None
Slovenia ^{m,q} (2015)	No	None
Spain ^{n,r} (2012)	No	None
Switzerland ^{o,r} (2017)	Yes	"Cave: too much sensitivity of flow-trigger could lead to auto-triggering of pressure support."
United Kingdom ^{p,r} (2010)	No	None

^a<https://transplant.goeg.at/sites/transplant.goeg.at/files/2017-06/Empfehlungen%20zur%20Durchf%C3%BChrung%20der%20Hirntoddiagnostik%20bei%20einer%20geplanten%20Organentnahme%20inkl.%20Protokoll.pdf>

^bhttp://www.ejustice.just.fgov.be/cgi_loi/change_lg.pl?language=fr&la=F&cn=1986061337&table_name=loi

^c<http://www.propisi.hr/print.php?id=3558>

^d<https://sfar.org/prise-en-charge-des-sujets-en-etat-de-mort-encephalique-dans-loptique-dun-prelevement-dorganes/>

^ehttps://www.bundesaeztekammer.de/fileadmin/user_upload/downloads/irrev.Hirnfunktionsausfall.pdf

^f<https://net.jogtar.hu/jogszabaly?docid=99800018.EUM>

^g<https://www.jficmi.ie/wp-content/uploads/2015/06/ICSI-Guidelines-on-Brainstem-Death-and-Management-of-the-Organ-Donor>

^h<http://www.medicoeleggi.com/argomenti000/italia2008/400148.htm>

ⁱhttps://cne.public.lu/dam-assets/fr/publications/avis/Avis_21.pdf

^j<https://www.healthcouncil.nl/documents/advisory-reports/2006/04/11/brain-death-protocol>

^k<https://www.healthcouncil.nl/documents/advisory-reports/2015/06/10/determining-death-in-postmortal-organ-donation>

^l<http://www.actamedicaportuguesa.com/revista/index.php/amp/article/view/2194/1613>

^m<https://www.uradni-list.si/1/content?id=25189>

ⁿ<https://www.boe.es/buscar/doc.php?id=BOE-A-2012-15715>

^ohttps://www.samw.ch/dam/jcr:9f60a9e3-b52a-4584-aa10-3dbd39c6d9e5/richtlinien_samw_tod_organtransplantation.pdf

^p<http://www.aomrc.org.uk/publications/reports-guidance/ukdec-reports-and-guidance/code-practice-diagnosis-confirmation-death/>

^qRegular member of Eurotransplant

^rAgreements between Eurotransplant and other European organ exchange organizations (see <https://www.eurotransplant.org>)

"ventilator selfcycling" was found and in the other two, this phenomenon could be identified through analogous content-related wording. The fact that VAT can be entirely attributed to cardiac impulses or pulse synchronous impetus and that disconnection of the patient from the ventilator would support the objectification of VAT, are mentioned in 2 national guidelines (Germany and Ireland). The causal importance of the trigger sensitivity setting of the respirator is mentioned in the recommendations of Germany and Switzerland (■ Table 1).

Discussion

Prevalence and potential state of knowledge and education

Among 83 neurological and neurosurgical patients who met all clinical criteria for brain death, false triggering was found in a report in 4 patients (4.8%) [29]. In a later report, autotriggering was observed in 9 patients over a period of 15 months, representing an incidence of 10–12% extrapolated from an estimated collective of 50 patients who were declared to be brain dead each year [19]. In a retrospective evaluation of 672 cases (i. e. patients with absent brainstem reflexes except for spontaneous respiration on the mechanical ventilator), an algorithm designed to identify and correct VAT could have been used in 63 cases (9.4%) [13]. It is emphasized that this phenomenon is likely to occur more frequently than estimated and it is believed that VAT may remain undetected in an unknown number of cases; indeed, this clinical scenario does not seem to be uncommon, as other clinical experiences show [19, 29]. A factor for problems in the context with VAT could be the state of education and knowledge about this phenomenon. For example, in a simulation training of brain death determination by critical care fellows and neurology residents, only 22% of the 41 participants checked for spontaneous respirations and/or recognized VAT [15].

Reasons for the occurrence of VAT

There are different causes for VAT, one of which is the improper setting of the trigger thresholds under various constellations [2, 30]. The two main types of ventilator triggers currently available are the flow trigger and the pressure trigger [14, 21]. The flow-triggering mode uses a continuous base flow setting and a flow trigger threshold setting. If the flow measured at the exhalation valve drops below the predefined threshold (flow sensitivity in liters per minute), the ventilator will initiate the inspiratory phase of the breathing cycle [17]. In the pressure-triggering mode, the ventilator maintains a known pressure within the ventilator circuit and if the pressure drops below a predefined threshold (pressure sensitivity in cmH₂O) due to a patient inspiratory effort, the ventilator delivers an assisted breath [8]. In comparison, the flow trigger mechanism is more sensitive to cardiogenic autotriggering than the pressure trigger mechanism [14, 16, 29]. If the flow-triggering or pressure-triggering thresholds are decreased on the ventilator, the patient requires lower inspiratory efforts for the delivery of an assisted breath; however, reducing the trigger threshold increases the likelihood of false triggering of the respirator due to inadequate flow and pressure sensitivity [22]. Furthermore, VAT can be observed more frequently on new generation ventilators [29], as some have internal programming that allows assisted breaths to ensure oxygen supply to the patient during longer periods of apnea regardless of the trigger setting selected.

Extrinsic causes for VAT include excessive condensation (occurring in the ventilator circuit, especially when not using a heated-wire circuit), humidification (because secretions within the lungs and airways can be released by a heat and moisture exchanger or external heater humidifier with a heated-wire ventilator), endotracheal tube cuff inflation/endotracheal tube leak, leaks in all other ventilator circuit connections (from proximal or distal airways up to the ventilator sensor at the Y-piece), malposition of the inline suction catheter, chest tube leaks and random artifacts

Anaesthesist 2019 · 68:171–176 <https://doi.org/10.1007/s00101-019-0555-5>
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Ventilator autotriggering. An underestimated phenomenon in the determination of brain death

Abstract

Background. Ventilator autotriggering (VAT) may induce uncertainty in diagnosing brain death because it may falsely suggest a central respiratory drive in brain-dead patients where no intrinsic respiratory efforts exist. Since the lack of international standardization of brain death criteria contributes to the loss of potential donor organs, it is important to be aware of this phenomenon, which is a not well-known confounder in the process of diagnosing brain death.

Methods. The national official recommendations or guidelines for the determination of brain death and organ transplantation of 15 selected European countries (including all 8 member states of the Eurotransplant network) were evaluated with respect to VAT. In addition, a literature search (PubMed, Google Scholar) using the term “ventilator autotriggering”, synonyms or similar content-related wording was carried out.

Results. The VAT phenomenon was mentioned in 3 of the 15 official recommendations and guidelines on diagnosing brain death. The causes and management of VAT are presented in different ways in the reviewed official recommendations and guidelines. **Conclusion.** The phenomenon of VAT is inconsistently addressed in the national guidelines and recommendations for the determination of brain death and should, therefore, be included in future harmonized brain death codes. Detection and correction of VAT should be implemented as early as possible by a structured procedure. Additional training and information on this phenomenon should be made available to the entire intensive care unit staff.

Keywords

Brain death diagnosis · Ventilator autocycling · Cardiogenic respiratory oscillations · Apnea · Intensive care medicine

Ventilator autotriggering. Ein unterschätztes Phänomen bei der Bestimmung des Hirntods

Zusammenfassung

Hintergrund. „Ventilator autotriggering“ (VAT) kann zu Unsicherheiten bei der Feststellung des Hirntods führen, zumal es bei Hirntoten das Vorliegen eines zentralen Atemantriebes vortäuschen kann, obwohl eine Apnoe vorliegt. Infolge der international fehlenden Standardisierung der Hirntodkriterien mit dem potenziellen Risiko des Verlustes an Spenderorganen ist es bedeutsam, sich dieses Phänomens bewusst zu sein, da es ein erheblicher Störfaktor im prozeduralen Ablauf bei der Hirntodfeststellung sein kann.

Methode. Die offiziellen nationalen Empfehlungen/Richtlinien von 15 ausgewählten europäischen Staaten (davon alle 8 Mitgliedsländer von Eurotransplant) wurden in Bezug auf die Erwähnung des Phänomens VAT untersucht. Ergänzend wurde eine Literaturrecherche (PubMed, Google Scholar) zum Begriff „ventilator autotriggering“ und dazugehörigen Synonymen durchgeführt.

Ergebnisse. Hinweise auf das Phänomen VAT wurden in 3 der 15 untersuchten

nationalen Richtlinien zur Bestimmung des Hirntods gefunden. In den betreffenden Empfehlungen/Richtlinien sind jedoch die Verweise auf Ursachen und Management in unterschiedlicher Form dargestellt.

Schlussfolgerung. In den nationalen Empfehlungen/Richtlinien zur Bestimmung des Hirntods wird VAT nicht konsistent berücksichtigt und sollte demnach in angeglicher Form in zukünftigen Hirntod-Codes vermittelt werden. Erkennungs- und Korrekturmaßnahmen sollten frühzeitig in einem strukturierten Ablauf erfolgen. Die Informationsweitergabe ist in Fortbildungskonzepten für das gesamte intensivmedizinische Versorgungsteam vorzusehen.

Schlüsselwörter

Hirntodfeststellung · Ventilator autocycling · Kardiogene respiratorische Oszillationen · Apnoe · Intensivmedizin

Table 2 Concept for identification and correction of suspected ventilator autotriggering

Cause	Check	Options for correction
Cardiogenic respiratory oscillations	Synchronicity of pulse rate/ECG waveforms with the respiratory rate on the flow time or pressure waveforms on respirator monitor?	Change from flow trigger mode to pressure trigger mode (typically set at -2 cmH ₂ O) Increase of flow sensitivity in 0.5 lpm increments until assisted breath ceases or change pressure sensitivity to -2 cmH ₂ O Change of patient's position from supine in left lateral decubitus position (to suppress significant chest wall movements secondary to hyperdynamic precordium)
Leak in ventilator circuit	Does flow volume or pressure volume return to baseline?	Control and correction of ETT cuff pressure Ensure circuit connections are tight (if required replacement of ventilator circuit) Control of chest x-ray for pneumothorax (chest tube leaks) or bronchopleural fistulas Ensure that inline suction catheter is in position in conformity with the manufacturer's recommendations
Noise/artifact (due to vibrations or movements)	Flow sensitivity set at 2 lpm? Pressure sensitivity set at -2 cmH ₂ O?	Increase of flow sensitivity in 0.5 lpm increments until assisted breath ceases Change to -2 cmH ₂ O pressure sensitivity
Excessive condensation	Humidifier device adequately working?	Appropriate setting of heater temperature (use of heated wire circuit) Draining of excessive condensation

lpm liters per minute, *ETT* endotracheal tube, *ECG* electrocardiogram

or noise in the ventilator circuit (due to movement and vibrations) [8, 17].

The predominant intrinsic cause for VAT in connection with brain death are cardiogenic respiratory oscillations (CRO) [1–4, 6, 22, 29]. The physiological background of CRO is based on the interaction between the cyclic cardiac stroke volumes and the displacement of compliant air-filled lung tissue causing gas movement. As the heart ejects blood during systole, the intrathoracic volume decreases creating a negative intrathoracic pressure. The cardiac cycle and its cyclic variations in pulmonary blood flow [25] can lead to shifts in the intrapulmonary gas volume, which can alter the airway pressure and flow, inducing ventilator self-cycling in brain-dead subjects [1, 3, 6]. The occurrence of CRO in brain-dead patients is often associated with a hyperdynamic precordium [3, 4, 22].

Identification and correction

The procedures for identification and correction of VAT overlap with each other [13]. The spectrum of VAT detection measures ranges from simple but insensitive clinical maneuvers testing the patient for chest wall movements in phase with cardiac cycles, to a close assessment of the graphical waveforms of airway flow or pressure with more detailed waveform analysis [22], up to the more advanced technique of monitoring the neurally adjusted coupling of the bioelectrical diaphragm function to ventilator assistance [9]. A way to terminate false triggering is a change from the flow trigger mechanism to pressure trigger [29] because flow-triggered ventilation is more sensitive than pressure-triggered ventilation. A valuable additional tool for identifying potential VAT could be a differentiated algorithm developed by Henry et al. [13]. In summary, several factors that can be considered to cause VAT should be identified and corrected by various measures [1–3, 13, 22, 29] (Table 2).

Additional prospective research is, however, needed to determine how many cases of VAT can be identified and corrected by the proposed procedures. In the case of persisting uncertainty, a formal apnea test with disconnection of the patient from mechanical ventilation and observation of whether any respiratory effort or movement of the chest is recognizable is recommended in the literature [6, 19, 20, 29] and by some national guidelines (Table 1). As several complications (e.g. atelectasis, hypoxemia, cardiocirculatory instability) can occur during apnea testing with disconnection from the respirator and adapted procedures (e.g., continuous insufflation of oxygen using a flow-controlled non-rebreathing system and manual ventilation once to twice per minute) can be provided especially in the case of a potential lung donation. Estimation of cerebral blood flow by transcranial Doppler studies or computed tomography (CT) angiography may be considered if the apnea test cannot be performed in patients with a high risk of complications [18].

Potential implications of VAT

The occurrence of VAT can lead to uncertainty and emotional strain for the entire ICU team. Another important implication in the context of organ donation is a possible delay between the occurrence and the pronouncement of brain death [1, 3, 4, 8, 19, 30], as the clinical examination to determine brain death is usually performed only when all brain stem reflexes are absent, which includes the loss of spontaneous breathing due to the lack of an intrinsic respiratory drive [13]. Longer ICU management times for potential organ donors increase the risk of organ loss, mainly due to refractory cardiocirculatory instability [30]. This fact and the prolonged exposition to activated inflammatory mediators secondary to the initial brain lesion and the state of brain death may negatively influence the quality of function of allografts and graft survival [27]. Furthermore, unnecessarily prolonging the ICU experience for patients' families is an emotional stress that could be accentuated by the risk of

raising false hope of patient recovery. Finally, the total ICU resource utilization and the subsequent financial aspects are factors that should also be kept in mind [1, 3].

Role of recommendations and guidelines

The lack of standardization of brain death and organ donation criteria worldwide contributes to a loss of potential donors [7]. The aim of official recommendations for determining brain death is to help healthcare providers to increase their knowledge about brain death diagnosis and to strengthen public confidence that such findings will be made after a thorough and careful evaluation according to accepted medical standards [10]; however, there is variability in European national recommendations and guidelines and VAT is mentioned only in a few of them. Even in the guidelines of countries collaborating within a transnational network that facilitates the allocation and cross-border exchange of deceased donor organs, there is an inconsistency (see [Table 1](#)). Therefore, VAT should be addressed and communicated in the national recommendations in a harmonized manner for diagnosing brain death.

Conclusion

Ventilator autotriggering may induce uncertainty in diagnosing brain death because it can falsely indicate central respiratory drive in brain-dead patients where no regular respiratory efforts exist. This topic is addressed inconsistently in the national guidelines for the determination of brain death. In particular, as different countries cooperate in a cross-border exchange of donor organs, it should be the aim for the future to have harmonized brain death codes with the inclusion of VAT. Further prospective studies on algorithms and methods for the identification, avoidance and correction of VAT are necessary.

Practical advice

- Recognize VAT as a confounder in the determination of brain death that in ventilated brain-dead patients mimics spontaneous breaths where there are none.
- Consider the main causes for the occurrence of VAT:
 - Cardiogenic respiratory oscillations,
 - Leak in the ventilator circuit,
 - Noise/artifacts,
 - Excessive condensation.
- VAT can be avoided by appropriate setting of the trigger thresholds of the respirator.
- Due to its wide-ranging implications, it is important to identify and correct VAT as early as possible using a structured procedure ([Table 2](#)).
- Multidisciplinary clinical information and training should be provided for the entire ICU team.

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Acknowledgements. The authors would like to thank Prof. Michael Herbert MD (Head of Department of Anaesthesiology and Intensive Care Medicine, Medical University of Graz, Austria) for general support, PD Senta Kurschel-Lackner MD, Univ.-Doz. Sandro Eustaccio MD, Angela Schöpfer BA, Szabina Makai MD, Prof. Stefan Schulz MD, and Zsófia Goda for their support in translation of the national recommendations and Irene Schwarz for conducting the literature search for the study.

Funding. Open access funding provided by Medical University of Graz.

Compliance with ethical guidelines

Conflict of interest G. Schwarz, M. Errath, P. Delgado, A. Schöpfer and T. Cavic declare that they have no competing interests.

This article does not contain any studies with human participants or animals performed by any of the authors.

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Bertelsmann Stiftung: Deutschland hinkt bei Digitalisierung im Gesundheitswesen deutlich hinterher

In einer internationalen Vergleichsstudie der Bertelsmann Stiftung zur Digitalisierung im Gesundheitswesen schneidet Deutschland schlecht ab und landet auf Rang 16 von 17 untersuchten Ländern.

Deutschlands Gesundheitswesen könnte digitaler sein. Zu diesem Schluss kommt die Bertelsmann Stiftung in einer internationalen Vergleichsstudie. Darin wurde analysiert, wie aktiv die Gesundheitspolitik in den Ländern bei der Digitalisierung handelt: Welche Strategien gibt es, welche funktionieren? Welche technischen Voraussetzungen sind vorhanden und inwieweit werden neue Technologien tatsächlich genutzt? „Während Deutschland noch Informationen auf Papier austauscht und an den Grundlagen der digitalen Vernetzung arbeitet, gehen andere Länder schon die nächsten Schritte. Mediziner in Israel beispielsweise setzen systematisch künstliche Intelligenz etwa zur Früherkennung von Krebserkrankungen ein. Unsere Gesundheitspolitik muss entschlossener handeln als in der Vergangenheit und ihre Führungsrolle bei der Gestaltung der Digitalisierung weiter ausbauen – nicht als Selbstzweck, sondern zum Nutzen der Patienten“, erklärt Brigitte Mohn, Vorstand der Bertelsmann Stiftung.

Spitzenreiter haben effektive Strategie

Auf den ersten Rängen des Vergleichs landen Estland, Kanada, Dänemark, Israel und Spanien. In diesen Ländern sind digitale Technologien bereits Alltag in Praxen und Kliniken. So werden Rezepte digital übermittelt und wichtige Gesundheitsdaten der Patienten in elektronischen Akten gespeichert – Ärzte und Kliniken können direkt darauf zugreifen. In Estland und Dänemark können alle Bürger ihre Untersuchungsergebnisse, Medikationspläne oder Impfdaten online einsehen und Zugriffsmöglichkeiten für Ärzte und andere Gesundheitsberufe selbst verwalten. In Israel und Kanada sind Ferndiagnosen und Fernbehandlungen per Video selbstverständlicher Teil der Gesundheitsversorgung.

Neuheiten kommen nicht an

Die von der Bonner Forschungsgesellschaft empirica im Auftrag der Bertelsmann Stif-

tung erstellte Studie besteht aus zwei Teilen: einem Digitalisierungs-Index, für den Experten aus den untersuchten Ländern jeweils zu rund 150 Kriterien Einschätzungen abgegeben haben, und einer detaillierteren Analyse von 5 für Deutschland in dem Feld besonders interessanten Gesundheitssystemen. Für eine gelingende digitale Transformation im Gesundheitswesen ist demnach eine effektive Strategie, politische Führung und eine spezielle nationale Institution zur Koordinierung des Digitalisierungsprozesses wichtig. Erfolgreiche Länder gehen strategisch in pragmatischen Schritten vor und führen einzelne Prozesse wie das digitale Rezept nach und nach ein.

Agenturen für digitale Gesundheit

In 15 der 17 analysierten Länder, in allen außer Deutschland und Spanien, gibt es „Agenturen für digitale Gesundheit“ auf nationaler Ebene. Diese sind etwa für die Definition von technischen Standards und Datenformaten für die elektronische Patientenakte verantwortlich. Eigentlich hat Deutschland die ersten Schritte in Richtung Digitalisierung früh gemacht, so die Bertelsmann Stiftung. Bereits 2003 hat die Bundesregierung die Einführung der elektronischen Gesundheitskarte beschlossen. Außerdem gibt es seit vielen Jahren erfolgreiche digitale Pilotprojekte auf regionaler Ebene – beispielsweise die Notfallversorgung von Schlaganfallpatienten oder das Telemonitoring von Menschen mit Herzerkrankungen. Doch seien die neuen technologischen Möglichkeiten in Deutschland nicht bundesweit und für alle Patienten nutzbar. Im Alltag der Versorgung sei bislang wenig angekommen.

**Quelle: Bertelsmann Stiftung
(www.bertelsmann-stiftung.de)**