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doi: 10.1016/j.bja.2023.06.060
Advance Access Publication Date: 29 July 2023

Rogers' diffusion theory of innovation applied to the adoption of sugammadex in a nationwide sample of US hospitals

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Keywords: adoption; innovation; neuromuscular blocking agent; Rogers' curve; sugammadex

Editor— Everett Rogers' *diffusion theory of innovations* has been widely applied to examine the timeline for the adoption of new ideas in several domains ranging from agriculture to healthcare, but has not been used to better understand the adoption of new medications, technologies, and procedures in anaesthesia practice.[1,2] Rogers' curve, with time on the *x*-axis and the proportions of a population adopting a new practice on the *y*-axis (see Fig. 1), is bell-shaped with adopters predictably falling into five categories with the following proportions: innovators (2.5% of the cohort), early adopters (13.5%), early majority (34%), late majority (34%), and laggards (16%).[2] Slow adoption, long delays between the generation of evidence and its routine application in anaesthesia practice, remains common. Rogers' curve has utility in identifying barriers to uptake and in guiding comparative effectiveness research using large-scale real-world data. We explored the uptake of sugammadex within a large nationwide sample of US hospitals between January 2016 and June 2018, the 30-month period after approval by the US Food & Drug Administration (FDA). Large studies have characterised the uptake of sugammadex in the USA but are marked by heterogeneity in the mix of procedures and a focus on patient-level predictors of use.[3,4] We address this by focusing on a single common procedure where neuromuscular block and reversal is common, and we examine use at the hospital level (measured as proportions of patients receiving a drug, each month, at each hospital).

With approval from the Duke University Healthcare System institutional review board, under a data use agreement with Premier Inc. (Charlotte, NC, USA), we used the Premier Healthcare database as used in prior studies[3–5] to identify individuals 18 yr of age or more undergoing outpatient laparoscopic cholecystectomy (International Classification of

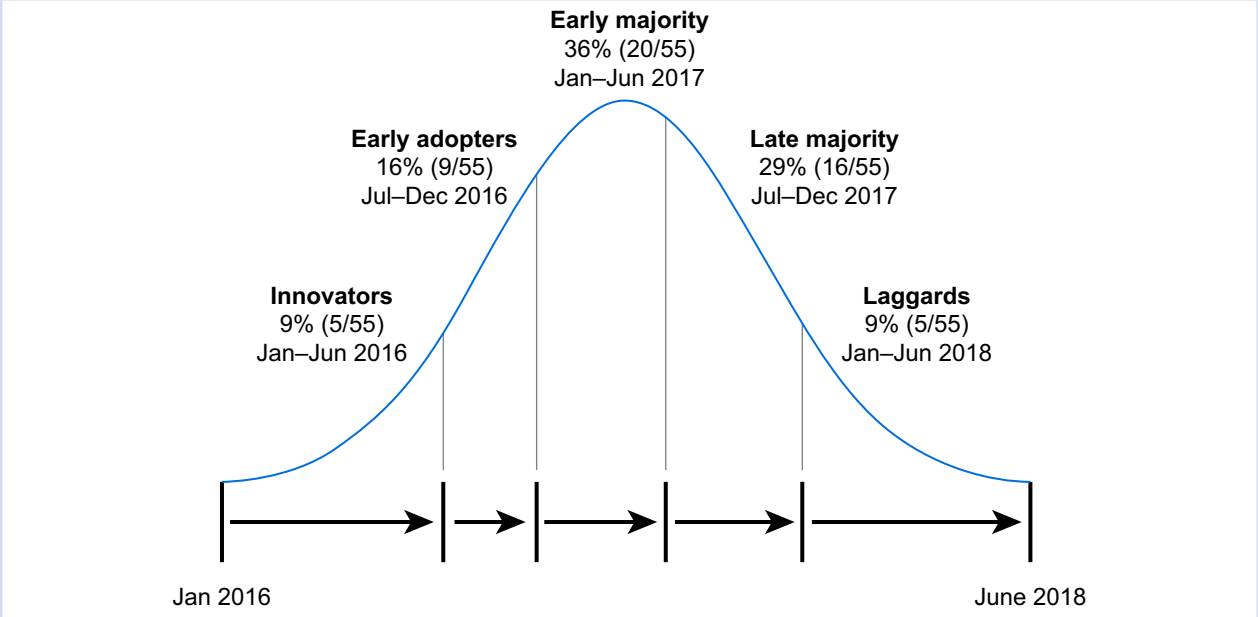

Fig 1. The Rogers' curve predicts the distribution over time of 55 US hospital sugammadex adopters. We calculated the proportions of patients who received sugammadex for the reversal of neuromuscular block among adults undergoing outpatient laparoscopic cholecystectomy each month between January 2016 and June 2018 (the 30-month period after sugammadex was approved by the US Food & Drug Administration). We identified 55 adopters (hospitals where sugammadex was used in >50% of patients each month for 6 consecutive months). The timeline for adoption was predicted by Rogers' diffusion theory of innovations.

Diseases, ICD-10, code 0FT44ZZ) at hospital outpatient departments where at least 50 such procedures were performed annually with >80% of patients receiving neuromuscular blocking agents (NMBAs) followed by reversal. We calculated the proportion of patients who received sugammadex every month at each facility and labelled hospitals as adopters when sugammadex use exceeded >75% for at least six consecutive months (i.e. sugammadex became the default choice for reversal of neuromuscular block). We then divided the 30-month period into five consecutive blocks of 6 months, and asked two questions. Firstly, could adopters be classified into five groups per Rogers' curve. Secondly, could progressive adoption be leveraged to conduct comparative effectiveness research. We previously capitalised on a natural experiment triggered by an FDA black box safety warning (rather than drug approval) to conduct a study on the comparative safety of treatment alternatives using difference-in-differences analysis. In a nationwide sample of hospitals, we first examined differences in the types of i.v. colloids used among adults undergoing orthopaedic surgery 1 yr before compared with after a black box safety warning on hydroxyethyl starch solutions, and then compared outcomes at hospitals that responded to the warning by switching from starch solutions to albumin after the warning compared with hospitals that continued to use starch before and after the warning.[5]

Among 146 hospitals where 80 570 adults had undergone outpatient laparoscopic cholecystectomy over the 30 months between January 2016 and June 2018, 55 had adopted sugammadex. At these 55 hospitals, more than half of patients (>50%) had received sugammadex (rather than an acetylcholinesterase inhibitor) each month for 6 consecutive months. Adoption proceeded at a variable pace, and as predicted by Rogers (Fig. 1) adopters fell into five categories. There were 91 non-adopter hospitals where sugammadex never became the default choice for reversal of NMBAs (Fig. 2 upper left panel). As expected, a natural experiment occurred at these adopter hospitals (Fig. 2, upper middle panel). The change from reversal with an acetylcholinesterase inhibitor to sugammadex occurred abruptly rather than gradually. By measuring differences in clinical and cost outcomes before and after the switch among switchers (difference 1 = the effect of changing from acetylcholinesterase inhibitors to sugammadex plus the effect of time) and measuring differences over the same time periods among the non-switchers (difference 2 = the effect of time), we obtain the effect of changing from acetylcholinesterase inhibitor to sugammadex by calculating the difference-in-differences.

Thus, using large-scale real-world data, we obtained minimally biased estimates of effectiveness and safety because it is implausible that other practices affecting outcomes (local culture, surgical techniques, anaesthetic approach) would change at exactly the same time as the change in type of reversal agent.[6] The main limitation of this study is that while inclusion of a diverse sample of US hospitals is nationwide, it is not nationally representative.[3,5] Secondly, we did not carefully measure practice changes

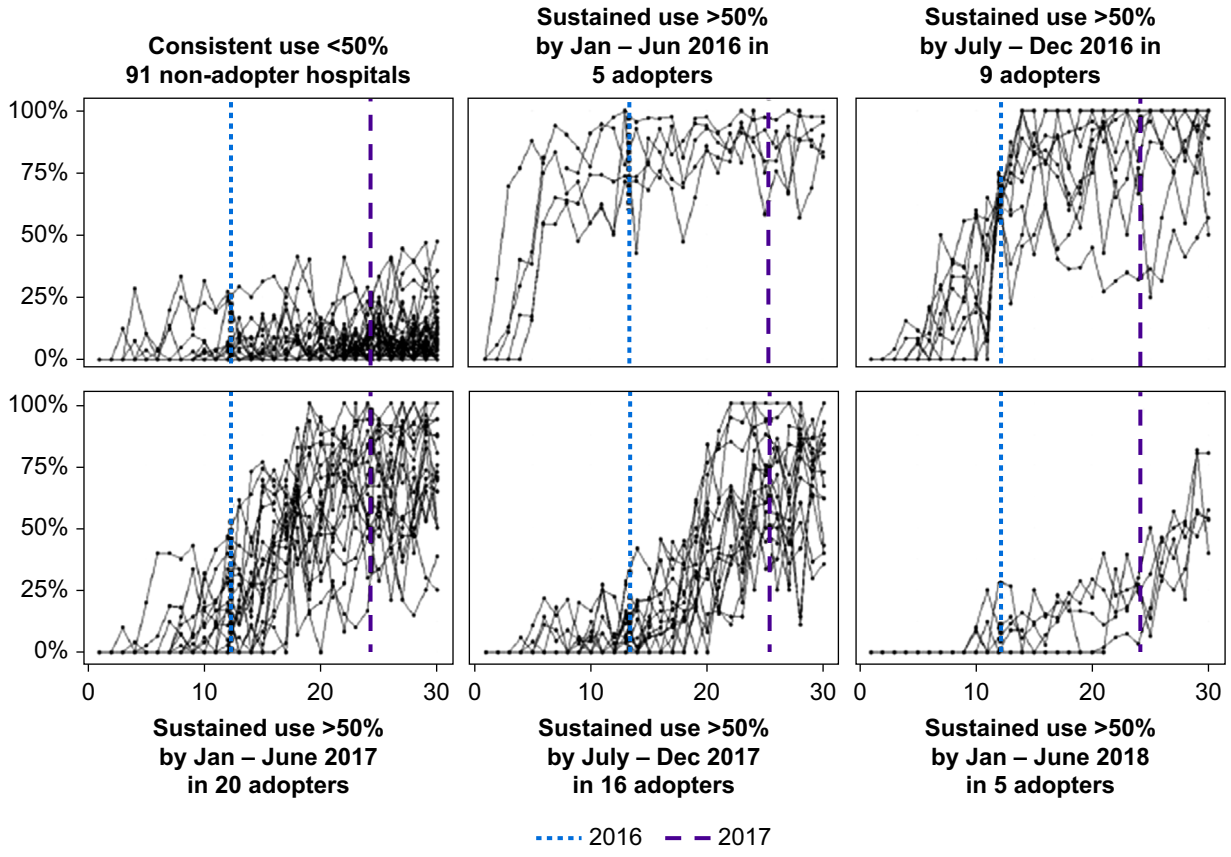

Fig 2. Natural experiments during the adoption of sugammadex. In all six panels, the *x*-axis shows time in months (between January 2016 and June 2018) and the *y*-axis shows proportions of patients who received sugammadex for reversal of neuromuscular block each month. Each hospital is represented by a line. In the upper left panel, sugammadex use remained below 50% (91 non-adopters). In the upper middle and right panels, and in the lower panel, sugammadex use reached >50% in successive 6-month periods.

potentially related to sugammadex (e.g. use of neuromuscular function monitoring). These limitations must be addressed in future studies.

Authors' contributions

Made contributions toward completion of this work and agree to be accountable for all aspects of the work: all authors
Conception: KR
Design: KR, MK, RB, VK, TO, JC
Acquisition of data: KR
Interpretation of analysis: KR, MK, MF, RJ, RB, VK, TO, JC
Drafting the work: KR, KP
Revising the work: KR
Final approval of the version submitted: KR, MK
Revising work for important intellectual content: KP, RL, RM, MF, RJ, SM, RB, VK, TO, JC
Analysis of data: MF, RJ

Declaration of interest

The authors declare that they have no conflicts of interest.

Funding

Research grant from Investigator-Initiated Studies Program of Merck Sharp & Dohme LLC, a subsidiary of Merck & Co., Inc., Rahway, NJ, USA [grant number 60736]. The opinions expressed in this paper are those of the authors and do not necessarily represent those of Merck Sharp & Dohme LLC, a subsidiary of Merck & Co., Inc.

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doi: 10.1016/j.bja.2023.06.061
Advance Access Publication Date: 28 July 2023

A retrospective observational cross-sectional study of intraoperative neuromuscular blocking agent choice and dosing in a US paediatric referral hospital before and after introduction of sugammadex☆

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☆This work was presented in part at the Society for Pediatric Anesthesiology Conference 2022 Annual Meeting, Tampa FL, USA in April 2022.

Keywords: neostigmine; neuromuscular blocking agent; reversal; sugammadex; suxamethonium

Editor—Sugammadex is a neuromuscular blocking agent (NMBA) reversal agent that has been widely adopted in anaesthesia practice, yet few data exist describing the relationship between its use and NMBA choice and dosing.[1,2] Use of an NMBA and deep blockade can improve surgical and tracheal intubation conditions in paediatric patients.[3,4] Sugammadex use is associated with reduced risk of pulmonary complications in adults.[5,6] Sugammadex permits reversal more rapidly and from a greater depth of blockade than neostigmine, including after a rapid sequence intubation dose of rocuronium.[7] However, improved outcomes are conditional on the use of a compatible NMBA and appropriate dose selection of both NMBA and reversal agent guided by adequate neuromuscular monitoring. Therefore, we explored whether choice and dosing of NMBA changed after the introduction of sugammadex in a quaternary US paediatric hospital. We hypothesised that a shift occurred towards sugammadex-compatible NMBAs, and that dosing of nondepolarising NMBAs increased.

Data were obtained from the perioperative research database at the University of Michigan. This study was approved by an institutional review board, and the requirement for consent waived (HUM00202790; University of Michigan, Ann Arbor, MI). The study protocol and statistical analysis plan were reviewed and approved *a priori* by the Anesthesiology Clinical Research Committee of the Department of Anesthesiology at the University of Michigan.

We performed a retrospective cross-sectional study in children undergoing general anaesthesia with tracheal intubation, January 1, 2014, through December 31, 2021 at the Hospital, to examine whether NMBA choice and dosing at induction, overall, and during the last 60 min before tracheal extubation changed after the institutional introduction of sugammadex on November 1, 2016. Anaesthetics before 2017 were grouped. Examination of dosing practices was further limited to patients receiving nondepolarising NMBAs. Note that practice changes occurred alongside institutional changes to medications supplied in the operating room and quality improvement efforts to improve neuromuscular monitoring.

Doses were expressed in mg kg^{-1} of actual body weight. As the selected dose of each NMBA differs because of differences in pharmacodynamics, we expressed dosing quantities as the number of 'standard medication-specific induction doses' defined as follows: cisatracurium 0.2 mg kg^{-1}, vecuronium 0.1 mg kg^{-1}, and rocuronium 0.6 mg kg^{-1}, based on literature and institutional practice, considering these to be equivalent.[8,9] Total case NMBA quantities were normalised to case duration. We fit generalised linear mixed models to measure changes in suxamethonium use and each dosing outcome. Models for suxamethonium use employed a logit link. Models for total case and induction dosing used an identity link. Zero-inflated Poisson models were used to evaluate NMBA dosing within the last 60 min before reversal as 69% of