Emerging Health Information Technologies

A list of health information technologies created following a review of the academic, commercial and grey literature for a workshop focused on identifying the patient safety challenges associated with emerging digital health technologies.

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|  | **Technology** | **Explanation** | **Examples** | **Key references** |
| 1 | Wearables | Sensors that are worn on the body in clothing or directly attached or imbedded. | Fitbit for heart rate monitoring (Benedetto et al., 2018); Actiwatch for sleep tracking (Danzig et al., 2020); Eating, activity and sleep (Crimarco et al., 2018) | Accuracy and metrological characteristics (Cosoli & Scalise, 2019) |
| 2 | Immersive technology, a.k.a. Virtual, Augmented and Mixed Reality | “*technologies that interact with, or leverage, the neuroscience of the human brain*” via computer-generated visualisations (Bremner et al., 2020) | Decision making (Kobayashi et al., 2018; Li et al., 2020); Neurology (K. H. Kim, 2016); Urology (Hamacher et al., 2016); Mental health (Freeman et al., 2017) | Reviews as applied healthcare (Bremner et al., 2020; John & Wickramasinghe, 2020); |
| 3 | Internet of Things an Industry Internet of Things | “*a network of devices all embedded with electronics, software, sensors, and connectivity to enable them to connect, interconnect, and exchange data*” (Wickramasinghe & Bodendorf, 2020) | Smart Continuous Glucose Monitors (Facchinetti, 2016); Parkinson’s disease monitoring via Apply Watch (Bot et al., 2016) | Managing the risks of IoT (Paxton & Branca, 2020) |
| 4 | A.I.-assisted clinical decision support | Any software that informs a clinical decision or prompts clinical action. | Sepsis (Komorowski et al., 2018 with critique by Habli et al., 2020) | Opinion on AI for CDS (Shortliffe & Sepúlveda, 2018); Methodological appraisal of A.I. approaches for suitability to CDS (Abbasi & Kashiyarndi, 2006; Aljaaf et al., 2015) |
| 5 | Drones | “*devices which are capable of sustained flight, which do not have a human on board, and are under sufficient control to perform useful functions*” (Scott & Scott, 2020) | Chronic disease in rural areas (S. J. Kim et al., 2017) | Review of drone-delivery models for healthcare (Scott & Scott, 2020); Review of drones in healthcare (Wulfovich et al., 2018); Challenges and opportunities of drones in healthcare (Amukele, 2019) |
| 6 | Mobile health app's and Patient Portals | Clinicians’ mobile access to electronic healthcare records, and patient access to their own electronic healthcare record. | Pharmacist-facing, medication-review app (Lu et al., 2017); Patient portal (McAlearney et al., 2016) | Gaps in mobile patient portal service to enable patient-centred care (Noteboom & Abdel-Rahman, 2020) |
| 7 | Swallowables | Technology that can be ingested | Local drug delivery (Goffredo et al., 2016), Imaging (Intzes & Meng, 2016), Diagnostics (Schmidt et al., 2019); General healthcare applications (Olano, 2019) | (Kalantar-Zadeh & Ward, 2019) |
| 8 | Mail-order prescription | Self-ordering pharmaceuticals online or using an online intermediary for clinician-prescribed pharmaceuticals | Amazon’s acquisition of PillsPacks; Capsule; NowRx | Centralised system (Kappenman et al., 2019); Adherence in mail-order and community pharmacies (Farley et al., 2019; Schwab et al., 2019) |
| 9 | Neural implants and interfaces | Embedded or surface devices sensitive to neural potentials that are used to inform or operate action | Neuralink; DARPA; Kernel; Facebook | An introduction (Fekete & Pongrácz, 2017); Challenges (Das et al., 2020; Koch et al., 2019) |
| 10 | Loneliness and social isolation | Any digital technology intended to reduce loneliness or social isolation | Geriatric (Poscia et al., 2018); General healthcare examples (Chen & Schulz, 2016) | Review of problems (Stojanovic et al., 2017); Planned review and meta-analysis of the effectiveness of digital interventions (Shah et al., 2019) |
| 11 | Blockchain | Open, decentralised, cryptographic ledgers | Prescribing (Seitz & Wickramasinghe, 2020); General healthcare examples (Agbo et al., 2019; Hölbl et al., 2018) | Challenges (McGhin et al., 2019) |
| 12 | Biohacking | D.I.Y., citizen-science, biological investigations and interventions | General healthcare examples (Zettler et al., 2019) | An introduction (Yetisen, 2018) |
| 13 | Digital Twin | “*a digital representation of a physical item or assembly using integrated simulations and service data*” (Vrabič et al., 2018) | General healthcare example (Angulo et al., 2019) | The technology, its applications, and the challenges (Fuller et al., 2019) |
| 14 | Omics | High-dimensional and high-throughput analytics. | Deep-learning example (Chaudhary et al., 2018); Attempt to combine large datasets (Karczewski & Snyder, 2018) | Technical review of methods (Bersanelli et al., 2016); Challenges (Cambiaghi et al., 2017; Gomez-Cabrero et al., 2014); Problems (Lay et al., 2006) |
| 15 | Conversational A.I. | “*systems that mimic human conversation using text or spoken language*” (Laranjo et al., 2018) | Apple’s Siri; Google Now; Microsoft Cortana; Amazon Alexa prize (Ram et al., 2018); Geriatrics (Fadhil, 2018b); Medication adherence (Fadhil, 2018a) | Perspectives on evaluation (Jadeja & Varia, 2017); A technical review (Gao et al., 2019); Review of applications in healthcare (Laranjo et al., 2018) |
| 16 | Commercial telemedicine | Remote provision of medical advice by commercial providers | Amazon.care; Apple’s AC Wellness; Diabetes (Garg & Parkin, 2019); Teledoc (Uscher-Pines et al., 2016) | General resource (Darkins & Cary, 2000) |

# Bibliography

Abbasi, M. M., & Kashiyarndi, S. (2006). *Clinical Decision Support Systems: A discussion on different methodologies used in Health Care*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.458.8844&rep=rep1&type=pdf

Agbo, C., Mahmoud, Q., & Eklund, J. (2019). Blockchain Technology in Healthcare: A Systematic Review. *Healthcare*, *7*(2), 56. https://doi.org/10.3390/healthcare7020056

Aljaaf, A. J., Al-Jumeily, D., Hussain, A. J., Fergus, P., Al-Jumaily, M., & Abdel-Aziz, K. (2015). Toward an optimal use of artificial intelligence techniques within a clinical decision support system. *Proceedings of the 2015 Science and Information Conference, SAI 2015*, 548–554. https://doi.org/10.1109/SAI.2015.7237196

Amukele, T. (2019). Current State of Drones in Healthcare: Challenges and Opportunities. *The Journal of Applied Laboratory Medicine*, *4*(2), 296–298. https://doi.org/10.1373/jalm.2019.030106

Angulo, C., Ortega, J. A., & Gonzalez-Abril, L. (2019). Towards a healthcare digital twin. In J. Sabater-Mir, V. Torra, & I. Aguiló (Eds.), *Artificial Intelligence Research and Development: Proceedings of the 22nd International Conference of the Catalan Association for Artificial Intelligence* (pp. 312-). Retrieved from https://books.google.co.uk/books?id=be-9DwAAQBAJ&source=gbs\_navlinks\_s

Benedetto, S., Caldato, C., Bazzan, E., Greenwood, D. C., Pensabene, V., & Actis, P. (2018). Assessment of the fitbit charge 2 for monitoring heart rate. *PLoS ONE*, *13*(2), 1–10. https://doi.org/10.1371/journal.pone.0192691

Bersanelli, M., Mosca, E., Remondini, D., Giampieri, E., Sala, C., Castellani, G., & Milanesi, L. (2016). Methods for the integration of multi-omics data: Mathematical aspects. *BMC Bioinformatics*, *17*(2). https://doi.org/10.1186/s12859-015-0857-9

Bot, B. M., Suver, C., Neto, E. C., Kellen, M., Klein, A., Bare, C., … Trister, A. D. (2016). The mPower study, Parkinson disease mobile data collected using ResearchKit. *Scientific Data*, *3*, 1–9. https://doi.org/10.1038/sdata.2016.11

Bremner, R., Gibbs, A., & Mitchell, A. R. J. (2020). The Era of Immersive Health Technology. *EMJ Innov*, *4*(1), 40–47.

Cambiaghi, A., Ferrario, M., & Masseroli, M. (2017). Analysis of metabolomic data: Tools, current strategies and future challenges for omics data integration. *Briefings in Bioinformatics*, *18*(3), 498–510. https://doi.org/10.1093/bib/bbw031

Chaudhary, K., Poirion, O. B., Lu, L., & Garmire, L. X. (2018). Deep learning–based multi-omics integration robustly predicts survival in liver cancer. *Clinical Cancer Research*, *24*(6), 1248–1259. https://doi.org/10.1158/1078-0432.CCR-17-0853

Chen, Y. R. R., & Schulz, P. J. (2016). The Effect of Information Communication Technology Interventions on Reducing Social Isolation in the Elderly: A Systematic Review. *Journal of Medical Internet Research*, *18*(1), e18. https://doi.org/10.2196/jmir.4596

Cosoli, G., & Scalise, L. (2019). Accuracy and Metrological Characteristics of Wearable Devices: A Systematic Review. In B. Andò, F. Baldini, C. Di Natale, V. Ferrari, V. Marletta, G. Marrazza, … P. Sciliano (Eds.), *Sensors: Proceedings of the Fourth National Conference on Sensors, February 21-23, 2018, Catania, Italy*. https://doi.org/10.1007/978-3-030-04324-7

Crimarco, A., Turner-McGrievy, G. M., & Wright, M. (2018). Use of Mobile Wearable Devices to Compare Eating, Physical Activity, and Sleep Between Individuals Following Vegetarian and Omnivorous Diets. *Journal of Technology in Behavioral Science*, *3*(4), 259–267. https://doi.org/10.1007/s41347-018-0060-8

Danzig, R., Wang, M., Shah, A., & Trotti, L. M. (2020). The wrist is not the brain: Estimation of sleep by clinical and consumer wearable actigraphy devices is impacted by multiple patient- and device-specific factors. *Journal of Sleep Research*, *29*(1), 1–10. https://doi.org/10.1111/jsr.12926

Darkins, A. W., & Cary, M. A. (2000). *Telemedicine and Telehealth: Principles, Policies, Performances and Pitfalls*. New York, NY: Springer.

Das, R., Moradi, F., & Heidari, H. (2020). Biointegrated and Wirelessly Powered Implantable Brain Devices: A Review. *IEEE Transactions on Biomedical Circuits and Systems*, *PP*, 1–1. https://doi.org/10.1109/tbcas.2020.2966920

Facchinetti, A. (2016). Continuous glucose monitoring sensors: Past, present and future algorithmic challenges. *Sensors (Switzerland)*, *16*(12), 1–12. https://doi.org/10.3390/s16122093

Fadhil, A. (2018a). A Conversational Interface to Improve Medication Adherence: Towards AI Support in Patient’s Treatment. *ArXiv*. Retrieved from http://arxiv.org/abs/1803.06000

Fadhil, A. (2018b). Beyond Patient Monitoring: Conversational Agents Role in Telemedicine & Healthcare Support For Home-Living Elderly Individuals. *ArXiv*. Retrieved from http://arxiv.org/abs/1803.06000

Farley, J. F., Urick, B. Y., & Schondelmeyer, S. W. (2019). Community pharmacy versus mail order: An uneven comparison. *Journal of Managed Care & Specialty Pharmacy*, *25*(6), 724–725. https://doi.org/10.18553/jmcp.2019.25.3.332.2.

Fekete, Z., & Pongrácz, A. (2017). Multifunctional soft implants to monitor and control neural activity in the central and peripheral nervous system: A review. *Sensors and Actuators, B: Chemical*, *243*, 1214–1223. https://doi.org/10.1016/j.snb.2016.12.096

Freeman, D., Reeve, S., Robinson, A., Ehlers, A., Clark, D., Spanlang, B., & Slater, M. (2017). Virtual reality in the assessment, understanding, and treatment of mental health disorders. *Psychological Medicine*, *47*(14), 2393–2400. https://doi.org/10.1017/S003329171700040X

Fuller, A., Fan, Z., & Day, C. (2019). Digital Twin: Enabling Technology, Challenges and Open Research. *ArXiv*. Retrieved from http://arxiv.org/abs/1911.01276

Gao, J., Galley, M., & Li, L. (2019). Neural approaches to conversational AI. In *Foundations and Trends in Information Retrieval* (Vol. 13). https://doi.org/10.1561/1500000074

Garg, S. K., & Parkin, C. G. (2019). The Emerging Role of Telemedicine and Mobile Health Technologies in Improving Diabetes Care. *Diabetes Technology and Therapeutics*, *21*(supplement 2). https://doi.org/10.1089/dia.2019.0090

Goffredo, R., Member, S., Pecora, A., Maiolo, L., Ferrone, A., Guglielmelli, E., … Accoto, D. (2016). A Swallowable Smart Pill for Local Drug Delivery. *Journal of Microelectromechanical Systems*, *25*(2), 362–370.

Gomez-Cabrero, D., Abugessaisa, I., Maier, D., Teschendorff, A., Merkenschlager, M., Gisel, A., … Tegnér, J. (2014). Data integration in the era of omics: current and future challenges. *BMC Systems Biology*, *8*(Suppl 2), I1. https://doi.org/10.1186/1752-0509-8-S2-I1

Habli, I., Lawton, T., & Porter, Z. (2020). Artificial Intelligence in Health Care: Accountability and safety. *Bull World Health Organ*, *98*, 251–256. https://doi.org/10.2471/BLT.19.237487

Hamacher, A., Kim, S. J., Cho, S. T., Pardeshi, S., Lee, S. H., Eun, S. J., & Whangbo, T. K. (2016). Application of virtual, augmented, and mixed reality to urology. *International Neurourology Journal*, *20*(3), 172–181. https://doi.org/10.5213/inj.1632714.357

Hölbl, M., Kompara, M., Kamišalić, A., & Zlatolas, L. N. (2018). A systematic review of the use of blockchain in healthcare. *Symmetry*, *10*(10). https://doi.org/10.3390/sym10100470

Intzes, I. G., & Meng, H. (2016). Design of wireless swallowable capsule with minimum power consumption and high resolution images. *Journal of Engineering Science and Technology Review*, *9*(6), 39–42.

Jadeja, M., & Varia, N. (2017). Perspectives for evaluating conversational AI. *ArXiv*.

John, B., & Wickramasinghe, N. (2020). A Review of Mixed Reality in Health Care. In N. Wickramasinghe & F. Bodendorf (Eds.), *Delivering Superior Health and Wellness Management with IoT and Analytics* (pp. 375–382). https://doi.org/10.1007/978-3-030-17347-0\_18

Kalantar-Zadeh, K., & Ward, S. A. (2019). Future is ready for swallowable sensors. *HepatoBiliary Surgery and Nutrition*, *8*(3), 267–269. https://doi.org/10.21037/hbsn.2018.12.13

Kappenman, A. M., Ragsdale, R., Rim, M. H., Tyler, L. S., & Nickman, N. A. (2019). Implementation of a centralized mail-order pharmacy service. *American Journal of Health-System Pharmacy : AJHP : Official Journal of the American Society of Health-System Pharmacists*, *76*(3), S74–S78. https://doi.org/10.1093/ajhp/zxz138

Karczewski, K. J., & Snyder, M. P. (2018). Integrative omics for health and disease. *Nature Reviews Genetics*, *19*(5), 299–310. https://doi.org/10.1038/nrg.2018.4

Kim, K. H. (2016). The Potential Application of Virtual, Augmented, and Mixed Reality in Neurourology. *International Neurourology Journal*, *20*(3), 169–170. https://doi.org/10.5213/inj.1620edi005

Kim, S. J., Lim, G. J., Cho, J., & Côté, M. J. (2017). Drone-Aided Healthcare Services for Patients with Chronic Diseases in Rural Areas. *Journal of Intelligent and Robotic Systems: Theory and Applications*, *88*(1), 163–180. https://doi.org/10.1007/s10846-017-0548-z

Kobayashi, L., Zhang, X. C., Collins, S. A., Karim, N., & Merck, D. L. (2018). Exploratory application of augmented reality/mixed reality devices for acute care procedure training. *Western Journal of Emergency Medicine*, *19*(1), 158–164. https://doi.org/10.5811/westjem.2017.10.35026

Koch, J., Schuettler, M., Pasluosta, C., & Stieglitz, T. (2019). Electrical connectors for neural implants: Design, state of the art and future challenges of an underestimated component. *Journal of Neural Engineering*, *16*(6). https://doi.org/10.1088/1741-2552/ab36df

Komorowski, M., Celi, L. A., Badawi, O., Gordon, A. C., & Faisal, A. A. (2018). The Artificial Intelligence Clinician learns optimal treatment strategies for sepsis in intensive care. *Nature Medicine*, *24*(11), 1716–1720. https://doi.org/10.1038/s41591-018-0213-5

Laranjo, L., Dunn, A. G., Tong, H. L., Kocaballi, A. B., Chen, J., Bashir, R., … Coiera, E. (2018). Conversational agents in healthcare: A systematic review. *Journal of the American Medical Informatics Association*, *25*(9), 1248–1258. https://doi.org/10.1093/jamia/ocy072

Lay, J. O., Borgmann, S., Liyanage, R., & Wilkins, C. L. (2006). Problems with the “omics.” *Trends in Analytical Chemistry*, *25*(11), 1046–1056. https://doi.org/10.1016/j.trac.2006.10.007

Li, Y., Li, J., Zhang, J., Ye, G., & Zhou, Z. (2020). medAR: An augmented reality application to improve participation in health-care decisions by family-based intervention. *Health Expectations*, *23*(1), 3–4. https://doi.org/10.1111/hex.12981

Lu, Y. H., Lee, L. Y., Chen, Y. L., Cheng, H. I., Tsai, W. T., Kuo, C. C., … Huang, Y. Bin. (2017). Developing an App by Exploiting Web-Based Mobile Technology to Inspect Controlled Substances in Patient Care Units. *BioMed Research International*, *2017*(December 2014). https://doi.org/10.1155/2017/3195369

McAlearney, A. S., Sieck, C. J., Hefner, J. L., Aldrich, A. M., Walker, D. M., Rizer, M. K., … Huerta, T. R. (2016). High Touch and High Tech (HT2) Proposal: Transforming Patient Engagement Throughout the Continuum of Care by Engaging Patients with Portal Technology at the Bedside. *JMIR Research Protocols*, *5*(4), e221. https://doi.org/10.2196/resprot.6355

McGhin, T., Choo, K. K. R., Liu, C. Z., & He, D. (2019). Blockchain in healthcare applications: Research challenges and opportunities. *Journal of Network and Computer Applications*, *135*(February), 62–75. https://doi.org/10.1016/j.jnca.2019.02.027

Noteboom, C., & Abdel-Rahman, M. (2020). Toward Actionable Knowledge: A Systematic Analysis of Mobile Patient Portal Use. In N. Wickramasinghe & F. Bodendorf (Eds.), *Delivering Superior Health and Wellness Management with IoT and Analytics* (pp. 587–602). https://doi.org/10.1007/978-3-030-17347-0\_29

Olano, C. (2019). Swallowable capsules are not only for videos. *Endoscopy International Open*, *07*, e782–e783.

Paxton, N. C., & Branca, D. L. (2020). Managing the Risks of Emerging IoT Devices. In N. Wickramasinghe & F. Bodendorf (Eds.), *Delivering Superior Health and Wellness Management with IoT and Analytics* (pp. 447–467). https://doi.org/10.1007/978-3-030-17347-0\_22

Poscia, A., Stojanovic, J., La Milia, D. I., Duplaga, M., Grysztar, M., Moscato, U., … Magnavita, N. (2018). Interventions targeting loneliness and social isolation among the older people: An update systematic review. *Experimental Gerontology*, *102*(December 2017), 133–144. https://doi.org/10.1016/j.exger.2017.11.017

Ram, A., Prasad, R., Khatri, C., Venkatesh, A., Gabriel, R., Liu, Q., … Pettigrue, A. (2018). Conversational AI: The Science Behind the Alexa Prize. *ArXiv*. Retrieved from http://arxiv.org/abs/1801.03604

Schmidt, A., Zimmermann, M., Bauder, M., Kuellmer, A., & Caca, K. (2019). Novel telemetric sensor capsule for EGD urgency triage: a feasibility study Authors. *Endoscopy International Open*, *07*, e774–e781.

Schwab, P., Racsa, P., Rascati, K., Mourer, M., Meah, Y., & Worley, K. (2019). A retrospective database study comparing diabetes-related medication adherence and health outcomes for mail-order versus community pharmacy. *Journal of Managed Care and Specialty Pharmacy*, *25*(3), 332–340. https://doi.org/10.18553/jmcp.2019.25.3.332

Scott, J. E., & Scott, C. H. (2020). Drone Delivery Models for Medical Emergencies. In N. Wickramasinghe & F. Bodendorf (Eds.), *Delivering Superior Health and Wellness Management with IoT and Analytics* (pp. 69–85). https://doi.org/10.1007/978-3-030-17347-0\_3

Seitz, J., & Wickramasinghe, N. (2020). *Opportunities for Using Blockchain Technology in e-Health: e-Prescribing in Germany*. 299–316. https://doi.org/10.1007/978-3-030-17347-0\_14

Shah, S. G. S., Nogueras, D., Van Woerden, H., & Kiparoglou, V. (2019). Effectiveness of digital technology interventions to reduce loneliness in adults: A protocol for a systematic review and meta-analysis. *BMJ Open*, *9*(9), 1–9. https://doi.org/10.1136/bmjopen-2019-032455

Shortliffe, E. H., & Sepúlveda, M. J. (2018). Clinical Decision Support in the Era of Artificial Intelligence. *JAMA - Journal of the American Medical Association*, *320*(21), 2199–2200. https://doi.org/10.1001/jama.2018.17163

Stojanovic, J., Collamati, A., Mariusz, D., Onder, G., La Milia, D. I., Ricciardi, W., … Poscia, A. (2017). Decreasing loneliness and social isolation among the older people: Systematic search and narrative review. *Epidemiology Biostatistics and Public Health*, *14*(2), 1–8. https://doi.org/10.2427/12408

Uscher-Pines, L., Mulcahy, A., Cowling, D., Hunter, G., Burns, R., & Mehrotra, A. (2016). Access and quality of care in direct-to-consumer telemedicine. *Telemedicine and E-Health*, *22*(4), 282–287. https://doi.org/10.1089/tmj.2015.0079

Vrabič, R., Erkoyuncu, J. A., Butala, P., & Roy, R. (2018). Digital twins: Understanding the added value of integrated models for through-life engineering services. *Procedia Manufacturing*, *16*, 139–146. https://doi.org/10.1016/j.promfg.2018.10.167

Wickramasinghe, N., & Bodendorf, F. (Eds.). (2020). *Delivering Superior Health and Wellness Management with IoT and Analytics*. https://doi.org/10.1007/978-3-030-17347-0

Wulfovich, S., Rivas, H., & Matabuena, P. (2018). Drones in healthcare. In H. Rivas & K. Wac (Eds.), *Digital Health: Scaling healthcare to the world*. https://doi.org/10.1007/978-3-319-61445-5

Yetisen, A. K. (2018). Biohacking. *Trends in Biotechnology*, *36*(8), 744–747. https://doi.org/10.1016/j.tibtech.2018.02.011

Zettler, P. J., Guerrini, C. J., & Sherkow, J. S. (2019). Finding a regulatory balance for genetic biohacking. *Consuming Genetic Technologies: Ethical and Legal Considerations*. https://doi.org/10.2139/ssrn.3490006