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Augmented Reality
and Virtual Reality
Medical Devices

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PEAC Executive Summary– Augmented Reality (AR) and Virtual Reality (VR) Medical Devices

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Introduction

Consider a hypothetical scene: A person who is standing in her living room puts on a head-mounted display, and suddenly finds herself seemingly inside a supermarket. Though the scene she perceives looks a bit like a cartoon, the sense of actually being in an aisle in this slightly cartoon-like store is complete; she can turn her head and body to look around in full 3-D, and everything she sees and hears adds to the illusion of physically standing in a market.

She perceives she is in the fruit section of the store, standing by a shopping cart. She now hears a voice encouraging her to reach out with her right arm in this virtual world, pick up an apple, and put it in the cart. As she lifts her arm there in her living room, she sees a realistic image of her hand moving out toward the apple. She squeezes her hand in real life, and the perceived hand follows suit, so that she is able to “grab” the apple, and then place it in the cart. The voice praises her success and encourages her to reach over and try to do the same with a nearby lime.

While this experience is hypothetical, it is based on a type of “virtual reality” rehabilitation therapy that is currently being offered to some patients who have experienced a physical disability associated with a stroke or other medical condition.¹

Virtual reality (VR) is a set of technologies that can be applied in a number of ways to diagnose and treat several different types of clinical conditions, in different ways, and with varying or as-of-yet unestablished success rates. The same is true of “augmented reality” (AR), a closely related approach. With VR, what the user sees and hears—usually through head-mounted gear that includes a display for each eye and tiny speakers—is a computer-generated, stereoscopic (3-D) simulation that is intended to completely replace the user’s perception of their actual physical environment. With AR, in contrast, the actual environment can still be seen and heard, making AR a less immersive experience, but computer-generated text, images and sounds can be superimposed onto or blended in with real sights and sounds. (The term “extended reality,” or AR/VR, is often enlisted to encompass the two approaches, but for the purposes of this discussion, we will use the term AR/VR.)

Central to AR/VR’s potential in diagnosis and treatment is its ability to deliver both standard and entirely new types of content in highly immersive and realistic ways, remotely, and at low cost. The result is the ability to deliver some types of clinical services—including some normally delivered only in clinics and hospitals—to patients in the comfort of their homes or other non-



clinical settings, with higher levels of engagement and utility compared to conventional telehealth on flat screens.²⁻⁵ That ability could enable patients, including those socioeconomically disadvantaged, to access needed health care services when accessing them in person would be difficult, and could increase adherence with treatment and monitoring regimens. Even when used with patients in clinical environments, AR/VR holds out the promise of delivering altogether new types of treatments and diagnostics, and improved or lower-cost versions of conventional ones. What's more, clinicians or in some cases caregivers can themselves enlist AR/VR's simulated environments to potentially improve their ability to prepare for or perform certain treatments or procedures.

It is also important to be cognizant of the risks and limitations of AR/VR technology, both in general and as applied to health care. Among the concerns worth considering: pediatric and cognitively impaired patients may be especially vulnerable to short- and long-term negative effects of AR/VR, and they may be less able to consent in an informed way to the risks and to weigh those risks against the benefits. Socioeconomically disadvantaged and other underserved populations may have less access to AR/VR approaches when they would be of benefit, or may be pushed into using them in cases when in-person care would be of more benefit; and while a number of studies have provided evidence that use of the technology may be cost-effective in some clinical applications,⁶ the question of cost-effectiveness remains largely unexplored for many other applications.

Applications and Benefits

There are a wide range of medical conditions and types of diagnoses and treatments to which AR/VR might eventually be applied. However, there are a number of treatment domains in which AR/VR has drawn special interest from clinicians and researchers, and in which AR/VR is already being used to treat patients.* Among those domains:

Mental health. For well over a decade, mental-health practitioners have been treating certain disorders with VR-based “exposure therapy.” Exposure therapy involves providing a safe environment for a patient to be presented with objects or situations that may tend to trigger or exacerbate fear, anxiety, stress, or other challenging mental states in that patient; the patient can then learn over time through these safe exposures to better tolerate exposures in daily life.⁷ Enlisting VR enables therapists to conjure up almost any type of simulated situation for the patient as a way of providing exposure therapy, including situations that may ordinarily be very difficult to simulate in a conventional clinical environment, such as those that recall wartime or other traumatic incidents.

* Except where otherwise explicitly stated, comments in this Executive Summary are not intended to be product-specific, nor to be used for product-specific regulatory decision-making. Also, please note that studies and other research cited in this Summary and not explicitly attributed to FDA, are included strictly for background.

Studies have found VR exposure therapy may be helpful in treating phobias, anxiety and post-traumatic stress, and there has been some exploration of its effectiveness in treating psychosis, autism spectrum disorder, and attention deficit hyperactivity disorder (ADHD),⁸ as well as eating disorders⁹ and schizophrenia spectrum disorder.^{†,10}

Neurological disorders. AR/VR has shown promise in numerous studies for physical, activities of daily living, and other types of rehabilitation with different neurological disorders. Stroke rehabilitation has been an especially promising domain for AR/VR, in part because stroke outcomes depend on how quickly rehabilitation therapies can be started, on the volume of therapy, and on how long the therapies can be continued. Limitations in facility and therapist availability and patient access to in-person clinical settings, along with the high cost of therapy, leaves many stroke patients with less than optimal courses of therapy. AR/VR can help close this gap by making therapy more accessible and lowering the cost.¹¹ As an adjunct to conventional therapy, AR/VR therapy shows evidence of improving physical function, cognitive function, and activity levels in stroke patients.¹² In individuals with stroke, Parkinson’s disease, or multiple sclerosis, home-based AR/VR rehabilitation therapy has also been shown to be effective in some studies in improving balance, gait, strength, motor function, and cognitive function, as well as in improving patient motivation and participation.¹³

AR/VR is also being studied in some neurological diagnostic applications. AR/VR could potentially present a more accessible way of assessing cognitive function in people who may have dementia or mild cognitive impairment, for example. Diagnostic procedures for these disorders often involve observing physical tasks and activities, as well as evaluating memory skills and eye movement, and clinicians don’t always have the time, equipment and space to conduct full assessments. These tests can be carried out in AR/VR often at lower cost and in any setting, with no need for additional equipment, and the results have been found to be about as effective in some studies as conventional versions of the tests.¹⁴

Managing pain. Numerous studies have suggested VR therapies can mitigate acute pain, and there is evidence they are effective in managing chronic pain.¹⁵ The approach is generally to enlist VR to distract and relax the user, typically with soothing sights and sounds, or engaging content that draws the user’s focus away from pain, apparently influencing both sensory and psychological components of pain perception.¹⁶ Studies have found the technique effective for pain associated with fibromyalgia, phantom limb syndrome, localized pain from injury and illness, surgical procedures, labor, wound-dressing changes, and chronic neck and lower-back pain, in both hospitalized patients and outpatients.¹⁶⁻¹⁸ In some studies, VR pain-management therapy outcomes are comparable to those of traditional physical rehabilitation approaches, as well as medication options, which can also have adverse side-effects.

†Note that other types of AR/VR therapies were also explored in treating schizophrenia spectrum disorder.

Diagnosing and treating pediatric conditions. In addition to positive findings in certain studies looking at applying AR/VR pain- and anxiety-management techniques to pediatric populations,¹⁹ some studies have found AR/VR-based therapies effective in improving upper-extremity function in children with cerebral palsy,²⁰ in helping children and adolescents with cancer psychologically adjust to hospitalization and treatment,²¹ and in diagnosing and improving behavioral outcomes in children with Attention-Deficit/Hyperactivity Disorder (ADHD).^{22, 23} The application of AR/VR to therapies for children with autism spectrum disorder is currently being studied.²⁴

Studies of the use of VR in ophthalmology for diagnosis, evaluation and therapy have produced mostly promising findings.²⁵ In particular, an VR-based therapy for amblyopia (lazy eye) aimed at pediatric use has been shown effective in studies,²⁶ and is the one ophthalmological VR application that has been granted by FDA for prescription use. In this therapy, the pediatric user watches content such as movies or cartoons in a VR headset, while the images displayed for each eye differ in ways that help balance the user's vision. Because the content can be made engaging, this therapy may achieve higher treatment adherence rates than the conventional treatment of wearing an eye patch or using drops.²⁷

Surgery. AR has the potential to improve pre-operative planning by allowing surgeons to examine 3-D visualizations of a patient's anatomy based on actual patient imaging, and to investigate different surgical paths and techniques.²⁸⁻³¹ These capabilities may better enable surgeons to more precisely identify structures within the surgical field, find alternative approaches to entry, enable less-invasive procedures, and in general to streamline workflow. Benefits may include shortened procedure times, improved outcomes, and decreased complications. Patients, too, may be encouraged to explore AR visualizations pre-operatively in order to better understand and become less anxious about the upcoming procedure, participate in decision-making related to the surgery, and anticipate postoperative side-effects and complications.

AR systems can even be used during a procedure to visualize progress in real time, and, especially if integrated with capabilities such as eye tracking, haptic (touch-related) feedback, gesture tracking and other response/feedback mechanisms, may enable surgeons to maneuver more precisely and effectively within the operative field. AR can also be enlisted to enhance image-guided surgery, in which the positions of the surgeon's tools are tracked in real time in the surgical field so that they can be superimposed on real-time patient imagery to provide a precise picture of the surgery's progress.³²

The ability to share these visualizations and other data remotely could make it easier and more effective for clinicians who are physically distant to consult on procedures. In the case of AR, surgeons can keep multiple data sources such as medical notes, images, and vital signs in their

field of view while operating, instead of having to look up from the surgical field to get the information on monitors.

What's more, the ability to train surgeons with less need for cadavers, animal models or on-site facilities may open up new opportunities for surgical specialty training in historically marginalized communities that suffer from shortages of specialists. AR/VR may also become an effective for ongoing surgical skills testing and refinement.

Concerns and Risks

There are risks associated with the use of AR/VR that have already been identified. Because the technology has not been in widespread use until relatively recently, the nature of these risks is not fully understood, and it is likely that other, not-as-yet-identified risks will emerge. The risks may be magnified in clinical applications, both because the risks are even less-well established and understood in clinical contexts, and because of the sensitivity of clinical applications along with the potential vulnerability of patients who might engage with those applications.

Below are some of the AR/VR-related concerns and risks that have been identified so far. It is important to note that little is known at this point about how these issues may present with different applications and impact different patient groups. What's more, there is more to learn about how setting limits on the frequency and duration of AR/VR sessions in a clinical application might be able to mitigate some of these concerns and risks, as well as whether those limits might reduce effectiveness.

Cybersickness. The most commonly reported negative side effect of AR/VR is motion sickness, often accompanied by dizziness, and in some cases by headaches and fatigue. In the context of AR/VR, these symptoms are sometimes lumped together under the term "cybersickness."³³ (AR tends to cause fewer problems along these lines than does VR.) Cybersickness can involve mild to intense nausea, up to the point of being temporarily incapacitating. Women (especially pregnant women), children, and older people are on average more susceptible to cybersickness.^{34, 35} Cybersickness is believed to be caused by a mismatch between the motion perceived visually in AR/VR, and the motion (or lack of motion) perceived by the inner ear. The problem tends to be worse in AR/VR applications that simulate more frequent, expansive and vigorous motion, and the problem tends to worsen with the length of the AR/VR session.

Collisions and falls. AR/VR users, and especially VR users, are frequently unable to see, or are distracted from noticing, some or all of their physical surroundings. When immersed in a fully or partly simulated AR/VR scene, users can collide with or strike real-life objects, furniture, walls, windows, or nearby people, or they may lose their balance and fall. As AR/VR has

become more popular in recent years, reports of such incidents and injuries and damages have increased dramatically.³⁶

Other discomfort and injury. AR/VR headsets tend to be heavy, with some popular models weighing close to two pounds. Wearing them can cause neck fatigue, and discomfort or even pain at or around the headset contact points. Aside from the physical discomfort of the headset itself, users can experience headaches and eye strain, as well as fatigue, discomfort and even pain in any of the many muscles or joints that may be repeatedly engaged during use. If use leads to extended periods of sitting or standing then users might be susceptible to leg or back or other postural and musculoskeletal fatigue, discomfort, or pain. Applications that require frequent looking around within simulated scenes could also lead to neck pain. AR/VR headsets typically are used with handheld controllers, and frequent pressing of the buttons and switches on these controllers could lead to problems with the hands and wrists, including repetitive motion syndrome.

There may also be more subtle, as-of-yet unidentified risks associated with the mismatch in AR/VR between a patient's physical sense of self, including their awareness of the position and location of their body, and what a patient experiences in AR/VR. For example, it may be difficult to predict where a patient's eyes will track while using AR/VR, and thus to predict what the patient will see, feel, and otherwise experience in an AR/VR application, and how that experience might interact with their physical awareness. It is important to understand how different patients react to these sorts of experiences and mismatches, and what impact these reactions have on clinical usage and outcomes.

Habitual usage. As with most devices that deliver content over screens, some users can find AR/VR extremely engaging; even therapeutic applications are often designed in the form of games and other appealing content. As with mobile-phone addiction and excessive television watching, AR/VR usage can be problematically habit forming. Such habitual and even addictive usage might raise the risks of and exacerbate the various other problems associated with usage, and could lead to neglecting other important activities, including physical exercise, social engagement, and routine daily tasks.

Seizures. Individuals at risk of photosensitive epilepsy may be susceptible to seizures triggered by AR/VR usage involving low-frequency flickering of images or brightness, whether the flickering is intentional within the content, or incidental due to poor system performance.³⁷ The risks of seizures may be higher with AR/VR devices than with other types of screen-based content delivery, because AR/VR engages the user's entire field of view rather than just a fraction of it, and thus stimulates a larger portion of the brain.³⁸ It should be noted that thus far studies in children haven't found an increased risk of seizure,³⁹ but such risk remains plausible.



Privacy violation. In addition to sharing all the data-privacy risks and challenges associated with computers and other electronic devices in medical applications, AR/VR presents unique concerns. Among these concerns are the fact that AR/VR devices typically use cameras and other sensors to track the user's bodily motions, surroundings, and in some cases facial expressions. What's more, the system correlates all this data with what the user is doing in virtual reality, potentially providing an unusually detailed picture of the user's behavior.^{40, 41} Any compromise could result in an impactful privacy breach.

Analyzing benefits and risks for AR/VR devices may be complicated by the relatively large number of risks that must be considered, by the potentially large impact of some of these risks (such as for pediatric neurodevelopment and for surgical precision), by the fact that most benefits and risks have not yet been clearly established in large, longitudinal or randomized studies, and by the fact that AR/VR devices are likely to be used (as discussed below) by different types of especially vulnerable populations in ways that may call for separate study.

Populations with Special Concerns

Pediatric populations. Given the greater brain plasticity and continuing brain development in children, the effects of AR/VR on the developing brain deserves special attention. Such effects are currently unknown. In particular, concerns about how AR/VR might impact the risks and extent of neurodevelopmental delays and disorders are warranted, especially in light of existing concerns about the possible relationship between usage of screen-based devices among children and neurodevelopmental delays,^{42, 43} and rising rates of pediatric neurological and mental health disorders, including autism, ADHD, anxiety, bipolar disorder, and psychosis.^{44, 45} The impact of AR/VR usage on pediatric visual development and associated visual acuity, may also be an issue.

More generally, the rapid cognitive, emotional, and physical development taking place in children, and how any or all of this development might be impacted by AR/VR usage, merits careful examination. Among the specific risks that can already be identified in pediatric populations: A higher risk of cybersickness; a limited ability to identify and articulate adverse events, and to react to them by reporting the events and limiting or discontinuing AR/VR usage; and a lack of appropriate fit and weight of AR/VR headsets in relation to young children's typically smaller heads and weaker necks compared to adolescents and adults. Children typically have smaller "interpupillary distances"—that is, the distance between the pupils of the two eyes—which is important for the fitting of glasses and other externally used, vision-based devices. The neuroplasticity of the pediatric brain magnifies any concerns associated with vision-related and other side effects due to poorly fitting headsets. There is also evidence that AR/VR might negatively affect a child's coordination by changing the way the brain weights different sensory inputs, such as vision and vestibular balance.⁴⁶

The impact of AR/VR use on the risk of seizures in certain pediatric populations may need further assessment. In addition, adolescents may be at increased risk of excessive or even addictive use of AR/VR. Children also tend to have more difficulty than do adults differentiating between reality and illusion, which could intensify the impact of any confusion, fear or other challenging emotion and cognition experienced in AR/VR. There may be other risks of AR/VR usage by children that have not been identified yet.

Cognitive impairment and mental health disorders. Cognitively impaired users may require a mode of AR/VR usage that minimizes demands on cognition, memory, and language skills.⁴⁷ These users may require additional training, assistance from a caregiver, or additional instructional prompts within the device itself. Some users with certain mental health conditions may also require special accommodations. For example, individuals who experience dissociative states, hallucinations, or other difficulties with perceiving reality may be frightened, confused or agitated by virtual content.

Surgeons. Some surgeons have become early users of AR as a tool to assist with surgical planning and procedures. Surgery can be extremely demanding in terms of precision, focus, awareness, and stamina, while often carrying high risks to patients associated with even small errors on the part of a surgeon. As a result, problems caused by AR use that might be considered of little concern in the general population could become serious in the context of surgery.⁴⁸

Even minor cases of side effects often associated with AR usage, including fatigue, nausea, discomfort, disorientation, misjudgment of distance, cognitive overload, distraction, the visual blocking or obscuring of nearby physical objects, and confusion between real and virtual images, could become dangerous if experienced even momentarily by a surgeon during a surgical procedure. Such AR-related impairments could also raise the risk of poor outcomes if experienced during AR-based surgical preplanning. Even relatively benign-seeming usage such as wearing AR glasses to superimpose data from monitors over the surgeon's field of view could lead to obscured views, or reduced performance due to the departure from highly familiar surgical routines.⁴⁹⁻⁵²

In addition, tactile- and sensory-feedback risks may arise in surgical robotics, such as miscalibration between virtual anatomical structures and the robotic placement of ports, screws, needles, and other operative devices. Also, there may be a risk that an AR/VR device isn't able to provide the high resolution and contrast needed to identify subtle differences in tissue types and extremely fine anatomical structures in high-precision surgical use cases.

Socioeconomically vulnerable populations. Socioeconomically vulnerable and other underserved communities and populations may lack equitable access to VR- and AR-based care. Clinical facilities local to these communities may not have the resources to acquire and



adopt the technology, and to provide clinician and user training; individuals may lack adequate health care insurance that covers the cost to patients of these technologies (especially in view of the fact that many payers have not yet fully embraced digital health technologies, though there are some exceptions⁵³); individuals may not have the resources to buy consumer AR/VR headsets that might be needed to run medical-care applications, and may lack the high-speed internet and the open floor-space required to operate AR/VR devices safely and effectively.

In other cases, individuals in underserved populations may be pushed into AR/VR versions of health care by providers or payers because of the potentially lower cost of such care, even if the risks and benefits of such care isn't fully established, and the individuals could be better served by conventional, in-person forms of care. In addition, individuals may not have the means to easily recognize and report problems with AR/VR-based care for various reasons, including language barriers. Such concerns may be amplified by the fact that vulnerable populations often present more widespread and complex health problems than others. As a result, the availability of AR/VR in diagnosis and treatment may amplify existing inequities in health care.

Ongoing Studies

VR and AR are relatively new and rapidly evolving technologies, and as such their risks and benefits are continuing to be studied. Nearly every study that has been conducted on these technologies points out that more research is required to answer key questions, including on effectiveness and safety. There are few, if any, studies that have looked at the long-term effects of AR/VR usage, the effects have not been studied on large numbers of diverse participants, and questions about “dosing”—that is, how the risks and benefits of using an AR/VR application change with the frequency and duration of use—have remained mostly unexplored. What's more, hardware, software, and applications vary widely, with new versions being introduced continuously, quickly rendering much existing research at least partly obsolete or irrelevant. These challenges are at least as applicable to medical usage of AR/VR as to other types of usage, if not more so, because applications are evolving particularly rapidly in health care.

AR/VR technology also presents inherent challenges to research.¹⁹ Most notably, it can be extremely difficult to conduct adequately controlled studies—for example, studies in which data from participants exposed to AR/VR treatments can be compared with data from participants who appear to receive the treatment but are not in fact receiving it. VR and AR are not easily simulated in a way that might leave both participants, those administering the treatments, and those evaluating its effects unsure of whether the treatment is real or sham.



AR/VR Hardware and Software

AR/VR requires hardware and software that are each unique to AR/VR and highly sophisticated. What's more, the hardware and software must work together seamlessly in order to provide the type of immersive, controllable, and consistent experience that is important to most AR/VR medical applications, as well as to minimize discomfort and other undesirable effects.

The essential task of a VR system is to project separate images into each of the user's two eyes to create the perception of a 3-D image, and then to synchronize the images to the head movement of the user to create the perception that the user is looking around through a full 3-D scene. An AR system, in contrast, lets the user look around at the actual environment, while projecting text or images into the user's eyes or onto a screen, so that it appears the content is superimposed on the actual environment. The text and images in AR devices may or may not be stereoscopic and may or may not be synchronized to head movement.

Generally, VR devices are head-mounted displays that include two tiny video displays, each placed three or so centimeters in front of one of the user's eyes; the images on the displays are magnified by intermediary optics, usually lenses. This setup creates a wide-field view of a stereoscopic virtual image in which objects and surfaces can realistically appear to be as close as a few centimeters from the user, or as far as kilometers away. The movements of the user's head, and in some cases the eyes, the hands, and the rest of the body, are tracked using a variety of sensors, and are used to update the virtual scene presented to the user. The head-mounted display can either be a standalone device, or tethered via cable to an external computer, and usually contains small speakers.

AR devices can be handheld or head-mounted. Handheld AR devices use either a mobile phone or a tablet to overlay virtual content onto a live video stream of the real world captured by the camera on the device. Head-mounted devices are sometimes less like the bulky goggles typical of VR devices, and closer to ordinary glasses. The real world can be seen either directly by using partially transparent optical components, or by using forward-facing cameras on the devices and projecting the image on near-eye displays along with the virtual images. In either case, text and images are then combined with the real-world images. AR devices may or may not include microphones and speakers.

AR/VR platforms usually enable integration of additional headset-mounted sensors, such as cameras, microphones, accelerometers, and light sensors, as well as control buttons, joysticks, and other haptic sensors embedded on handheld controllers. In some cases, external sensors, such as wall-mounted cameras, may feed data to the platform.

The software on AR/VR devices takes data from the sensors and from external networks and uses the data to update the visual and audio content presented to the user in real time. While sensor data is usually dedicated to updating what the AR/VR users sees and hears, the data

can also be used to provide haptic feedback, allowing the user to physically feel interactions with virtual objects and surfaces. In current systems, that feedback is typically limited to vibrations in the hand-held controllers, but future hardware may include various devices that can apply mild forces so as to provide, for example, a sense that a virtual apple “picked up” by a user in AR/VR has a physical volume and weight. In surgical applications that haptic capability could allow surgeons to plan a procedure while experiencing a realistic sense of the difference between soft tissue and bone, among other advantages.

In general, both VR and AR devices require high-speed wireless internet connections to stream digital information such as medical images to the device, and to communicate with other devices. An onboard computer chip, which may be assisted by a connection to a nearby computer to which it is tethered, or to cloud-based computing services, does substantial processing to create and update images.

Many AR/VR devices provide hardware and software that optionally enable a third party, such as a provider, parent, or other caregiver, to access the sights and sounds that an AR/VR user is experiencing through the headset. These images and sounds are typically shared on a phone, computer display or television screen, meaning they lack the immersive experience provided by wearing an AR/VR headset, but allow observing the content and information that the AR/VR user is experiencing. In most applications, the software will ask for the AR/VR user’s explicit consent before enabling sharing.

Human Factors Design Issues

Human factors engineering in the context of devices is the process of applying knowledge about human physical, sensory, emotional, and intellectual capabilities and limitations to device design and development. That process could make VR and AR systems more intuitive and easier to use, and may reduce the risks of using them, as well as amplify their benefits.

For the benefit and protection of patients and other users, as well as to meet certain FDA requirements,⁵⁴ device and software developers often include human factors and usability design principles in the design and development of medical devices. For medical device developers, there are many other benefits to incorporating these principles into the design and development of a medical device, including the potential for reduced time to market, increased sales, the reduced need for customer support of devices with user-friendly designs, and better adherence rates for usage of the technology.⁵⁵ Incorporating human factors and usability engineering is an iterative process. One aspect of that process involves defining the intended users of the medical device and understanding the user characteristics that could impact their safe and effective use of the device.

Use errors and hazardous situations identified through the human factors and usability engineering process should be taken into consideration when designing all aspects of the device-user interface. These aspects include all points of interaction between the user and the device's physical and software components, such as labeling, instructions for use, elements that provide information to the user, and the logic of the overall user-system interaction.⁵⁶

There are typically three recommended approaches to mitigating use-related risks. In order of priority, they are: inherent safety by design, protective measures in the device, and/or information for safety.⁵⁷ Some of the risks and concerns regarding AR/VR platforms can be directly mitigated through proper design. Discomfort associated with headset weight and contact pressure, for example, can be lessened in a straightforward way by providing headsets with the adjustability needed to enable most users to achieve a comfortable fit.

Cybersickness and eye-strain risks and intensity can be reduced by enabling both hardware and software adjustment of the positioning of the two near-eye display screens relative to each other and the eyes so as to suit a user's interpupillary distance. These side effects can be further reduced by increasing display resolution and frame rate—that is, how rapidly the displays can be refreshed to smooth out on-screen motion and flicker—as well as by reducing image “latency,” or the lag between the user's head movement and the updating of the image to respond to that movement.

Software application design can help as well. Applications can reduce the frequency and intensity of both user and image motion to lower the risk of cybersickness and collision with physical objects and surroundings. They could also monitor dosing, by limiting the time that a user can remain active in an application before closing down or providing a warning that encourages the user to close the application. These dosing limits could be adaptive, by being stringent for a new user, and increasingly less so as the user shows signs of becoming less sensitive to the negative effects of AR/VR with ongoing usage. These design considerations can also be adaptive to more vulnerable users, including children, older individuals, and individuals with cognitive or other impairments.

Warnings can help, too. Consumer AR/VR hardware and applications currently typically provide warnings that they are not intended for users who are younger than 13⁵⁸ (though the basis for this age limit is unclear), that users who are susceptible to flashing or flickering lights and images may experience seizures, and that some users may experience other uncomfortable effects. They also typically guide users through setting up a virtual “wall” around the physical area that can provide a visual warning if a user moves too close to surrounding objects and surfaces.

But there are opportunities to strengthen these warnings and safeguards and better integrate them with applications to provide additional warnings and reminders when a user is at particular



risk of uncomfortable effects or unsafe actions. Applications could also solicit frequent feedback from users about the extent to which they may be feeling uncomfortable or unsafe and respond accordingly. An application could even require that a user supervisor such as a clinician or caregiver be verifiably present. What's more, warnings, safeguards, and training modules could be adaptive to a user's vulnerability, experience, digital literacy, and health literacy, as well as to indications that a user may in some way be struggling to engage with the application safely and effectively. An AR/VR platform could also incorporate biometric security devices to reduce the possibility of the device being used by an unintended user.

How FDA Regulates AR/VR Medical Devices

Premarket Evaluation

Generally for a medical device to be legally marketed and sold in the United States, FDA must first review safety and effectiveness data for the device and weigh the benefits of using the medical device against any risks of using the medical device.^{59, 60} Based on its analysis, FDA then makes a decision about authorizing the device to be marketed.

The calculation of benefits and risks can be complicated. Commonly considered benefits include:

- The degree to which the medical device helps patients experience clinical improvements, lower risks, receive a more accurate diagnosis, or undergo shorter procedures, and the likelihood that patients will experience those benefits.
- How long the benefit can be expected to last.
- Improvements that benefit health care professionals or caregivers, such as shorter procedural times, and better training.

Commonly considered risk factors include:

- Deaths and serious injuries and impairments attributable to the use of the medical device, or the need for medical intervention to prevent such harms.
- Adverse health events and complications that don't rise to the level of possible death or serious injury—for example, a diagnostic medical device that provides unexpectedly unreliable results, leading to patient overtreatment or undertreatment.
- Medical device malfunction or underperformance, even when adverse health events do not result. An example might be a diagnostic medical device that provides unreliable results, though those false results do not result in treatment decisions that adversely impact health.



- Risks that impact health care professionals or caregivers, such as the need to invest extra time and training in the use of the medical device without deriving any benefit from that investment.

In considering benefits and risks, FDA also considers additional factors, including:

(1) patient preferences

This includes the extent that testing with the device reflects values and outcomes that are important to patients, including outcomes and metrics that are important to patients as well as whether some patients (or a specific group of patients) prefer attributes of the device. Different stakeholders may judge the benefits and risks of a medical device in different ways. FDA also relies on the clinical expertise of health care providers to help determine and weigh medical device benefits and risks, as well as on the perspectives of patients.

(2) uncertainty

This includes the confidence that FDA has that the data provided reflect what will occur in real-world usage, based on the quality of the data that is collected, statistical analysis, and clinical/scientific judgment. Uncertainty can be a challenge. When a medical device has been used by relatively small numbers of patients, data on medical device usage may be limited. The result may be a relatively high level of uncertainty around the benefit-risk profile. Different patients may interpret a given level of uncertainty in different ways. In the case of AR/VR devices, the medical device under review may either be hardware and software combined and developed specifically for a medical purpose, or it can be an off-the-shelf commercial AR/VR headset with custom software intended for a medical purpose.

(3) the extent to which the device fulfills an unmet medical need.

FDA has implemented programs aimed at promoting timely patient access to innovative devices and device-led combination products. One such program is the Breakthrough Devices Program, which is intended to expedite the development, assessment, and review of certain devices that meet the designation criteria for the program, including providing for more effective treatment or diagnosis of life-threatening or irreversibly debilitating diseases or conditions.⁶¹ AR/VR devices that apply for and are granted Breakthrough Device designation can utilize the features of the program to support more timely and collaborative interactions with FDA and reach mutual understanding of data collection expectations, adding efficiency, predictability, and transparency to the device development process. Other features of the program include applying efficient and flexible approaches for clinical study designs and enhanced opportunity for postmarket data collection. AR/VR devices have successfully been granted Breakthrough Device designation and have gone on to obtain marketing authorization.

As part of a marketing authorization decision, FDA will typically mandate that labeling⁶² be provided with the device. Labeling is information provided to help users (e.g., patients or caregivers) understand how to use the device, as well as provide safety information. Note that while labeling may be necessary so that users understand how to use the device and its benefits and risks, labeling may not completely mitigate the risks of device use. FDA considers the limits of labeling in its benefit-risk thinking. Labeling may also include information regarding the training needed to use the device safely and effectively.

Special Considerations Relevant to AR/VR Devices

In collecting clinical data to support safety and effectiveness for AR/VR devices, informed consent^{63, 64} is a critical part of testing medical devices safely and ethically. It is important to inform patients about not only the benefits of a new AR/VR device, but also its risks, including any uncertainties the designers of the clinical study might be aware of. Further, additional safeguards to protect vulnerable patients involved in AR/VR device studies may be necessary. For example, children are a vulnerable population who cannot consent for themselves, and so FDA's requirements include additional safeguards for studies involving children.⁶⁵ FDA is interested in getting multiple perspectives on the benefits and risks of AR/VR devices not only for its own decision-making, but also to help patients in making informed decisions about joining AR/VR device clinical trials.

Relative to current therapies, an AR/VR device may introduce benefits, including those discussed in this document. The benefits may be identified across a wide variety of patients, or it may be more beneficial for some patients than others. For example, a device may demonstrate particular benefit for underserved populations (e.g., patients with more limited access to medical care) or vulnerable populations (e.g., children). However, an AR/VR device may have risks as well, including risks related to the usability of the device (such as neck pain from the weight of the headset), and risks related to AR/VR technologies (such as dizziness, fatigue, or effects on vision).

For a novel device, the risks and benefits are examined by FDA mostly through a submission called a De Novo request. The De Novo request provides a marketing pathway to classify novel medical devices for which general controls alone, or general and special controls, provide reasonable assurance of safety and effectiveness for the intended use, but for which there is no legally marketed predicate device. De Novo classification is a risk-based classification process.⁶⁶

In some cases, existing devices can add AR/VR as a capability and provide robust data to show that they continue to be as safe and as effective as other similar devices. FDA makes that determination (called "substantial equivalence") through a submission to FDA called a 510(k) premarket notification.⁶⁷ Whether De Novo or 510(k), bench testing and clinical testing may be

needed to support FDA's decision-making. FDA also has recommendations for how high-quality Real-World Evidence (RWE) can be leveraged to support regulatory decision-making.⁶⁸

FDA also considers how device software functions may be used with consumer product hardware and/or software, and applies Additional considerations arise over the fact that many or even most AR/VR medical applications are being built on or integrated with consumer hardware and software. As a result, FDA's Multiple Functions Device Policy, when appropriate. Applying this policy, applies, means that during FDA review of an AR/VR medical device product FDA may assess the impact of the consumer hardware and software on the safety and effectiveness of the device function when used as a medical device.

When making benefit/risk determinations, FDA considers the totality of the evidence, including the extent of uncertainty in the benefit-risk information. FDA also considers the appropriateness of risk mitigations and the collection of postmarket data to address the uncertainty in the benefit-risk information. This could include collecting additional data in the postmarket setting, rather than premarket, to address the greater uncertainty about the device's probable benefits and risks, provided that the statutory standards for premarket approval are met.⁶⁹ When making a determination of whether it is appropriate to collect certain data in the postmarket setting, rather than premarket, FDA considers, among other factors, the device's potential impact on public health. FDA may approve a device with a greater degree of uncertainty regarding the benefits and risks of the device if this uncertainty is sufficiently balanced by other factors, including the probable benefits of the device and the extent of postmarket controls.⁷⁰

Postmarket Oversight

The FDA is committed to improving public access to accurate and transparent medical device reports and to quickly address any data and/or entry errors. The FDA uses a variety of methods to monitor the safety of a device after it is on the market, including postmarket studies, medical device reports (MDRs or adverse event reports), inspections, recalls, active surveillance of certain devices, and ongoing research and data analysis of medical journals, electronic health records systems, patient registries and administrative and insurance claims. FDA issued its Medical Device Safety Action Plan⁷¹ including key actions to encourage innovation to improve medical device safety, to increase ability to detect real-world safety risks earlier, and to keep patients and healthcare providers better informed.

FDA uses a balance of premarket and postmarket evaluation to ensure safety and effectiveness. Postmarket studies may be especially useful for AR/VR devices, given that premarket reviews for some of these devices may be of a shorter timeframe and the risks of emerging technology may be not fully understood. Postmarket studies of AR/VR devices can be used to evaluate the long-term safety and effectiveness, longitudinal risks, higher-severity risks such as impacts to neurological or visual development and mental-health implications as well as to identify unanticipated issues.



In certain circumstances, FDA can mandate that the device be studied to monitor safety and effectiveness while it is on the market. These circumstances include but are not limited to, evaluating the device in certain populations, such as patients at risk of serious illness or injury, children, and other vulnerable populations. Because some AR/VR devices may have significant use in pediatric populations, FDA would likely have the authority to mandate studies for those devices under the Section 522 Postmarket Surveillance program.⁶⁹ These studies would be closely monitored by FDA to ensure they are conducted and reported in an appropriate and timely manner.

Another important tool for postmarket surveillance is Medical Device Reporting (MDRs)⁷⁰ by patients, health care professionals, and manufacturers. MDRs can be viewed publicly through the Manufacturer and User Facility Device Experience (MAUDE) database.⁷² Other avenues for collecting and analyzing postmarket data include registries maintained by professional medical societies and postmarket studies conducted by industry and academic medical institutions.

Currently, MDRs are the primary mechanism for postmarket medical-device reporting. But because AR/VR devices and applications may be intertwined with consumer hardware and software, these FDA reporting requirements may not always clearly apply. It may be that other steps are warranted to ensure that providers, patients, and caregivers are encouraged to report adverse events and other problems and are informed how to best submit such reports. In some cases, other government agencies, the Federal Trade Commission (FTC) or the Consumer Product Safety Commission (CPSC) may receive the adverse event reports. The FTC enforces the FTC Act, which prohibits deceptive or unfair acts or practices in or affecting commerce, including those relating to privacy and data security, and those involving false or misleading claims about product safety or performance. The FTC may solicit and receive reports about problems with AR/VR devices that are relevant to medical applications. The CPSC, in its efforts to reduce the unreasonable risk of injuries and deaths associated with consumer products, uses a system for reporting issues (<https://www.saferproducts.gov/>).

Because of the various challenges that AR/VR technologies present to fully identifying and analyzing problems and risks, some of which may prove to be as-of-yet unforeseen, FDA may take additional actions to ensure the continued safety and effectiveness of the device. For example, after learning of a health risk, FDA may request a device manufacturer to update the device labeling, to recall the device, to further study the device while on the market, and/or to submit a premarket submission if the device is modified to address the identified issue.

In Summary

There is more to learn about the risks and benefits of AR/VR, about how to calculate and weigh those risks and benefits for different devices, software, applications, and populations, and about



how best to communicate guidance, warnings, and other information to patients, practitioners, and caregivers. These questions all merit careful study and consideration.



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