

# The Role of Using Concussion Detection Sensors in Healthcare Management

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**Abstract:** Concussion is a critical brain condition which may lead to temporary loss brain function. Commonly, it is related to sport activity and accidents where around 57 million people around the world suffering from traumatic brain injury. Application of sensors technology promotes early detection of concussion and playing a significant role in clinical diagnosis and management. As well as, telemedicine provides a smart solution for detection and management of Concussion over remote area.

**Keywords:** Concussion sensor, Concussion detection and management, Telemedicine, Connected Health.

## Introduction

Concussion is one of the most critical brain injury commonly related to sports activities. Also, it can be resulted from vehicle accidents affecting part of the community. High ratio of concussion injuries among all ages found in young children participated in sport activities due to the disproportionately of their heads are large compared to their growing body at this certain age. On the other hand, Large ratio of people who are suffering from concussion don't experience and recognize any indicators or symptoms. Making the detection of concussion is crucial and require special care to diagnoses and management. Impact of technology into the healthcare services provide a great promoting solution to early detection of concussion. As same as, improve and develop diagnosis techniques and management solutions based on telemedicine and smart technology. Therefore, in this review I would discuss the potential using of sensor and medical devices to detect signals and data required to diagnose concussion and explore commercial systems that are used to support and manage patients.

## Definition and overview

Concussion can be defined as a complex of pathological conditions affecting the brain leading to traumatic brain injury with temporary loss of functions by direct blow to head or by impulsive force shaking the head and upper part of the body causing temporary neurological impairment including physical (e.g., headaches, nausea), cognitive (e.g., difficulty with concentration or memory), emotional (e.g., irritability, sadness), and maintenance (e.g., sleep disturbances, changes in appetite or energy levels) symptoms. Sport and physical activities are responsible for more than 15% of head and spinal cord injuries, as the popularity of sport rises it is suggested to increase the incident of sport related injuries (McCrorry et al. 2009). Human brain protected by skull bone and surrounded by cerebrospinal fluid functioning as shock absorber for small blow forces. Acceleration and deceleration of head can cause a concussion when the brain bump to the anterior part of the skull as a reaction to the impact force. While in the case of deceleration the brain hits the opposite side of the skull. Rotational movement of the brain inside calvaria producing shear forces that establish torque leading to concussion.

Symptoms and indicators of concussion are divided into temporary and delayed signs; the common temporary symptoms headaches or feeling of pressure, dazed feeling, confusion, vomiting and loss of memory (amnesia). Other types of symptoms may be delayed for hours or days after injury such as sensitivity to light and noise, sleep disturbance and concentration complaints. Moreover, researches (Daneshvar et al. 2011) exposed that a relation between concussion and long term effects may lasting decades certainly for patients with previous treated concussion. A recent study showed that after three decades of concussion injured athletes had medical indicators and symptoms comparable to patients with early Parkinson disease (MNT, 2013).

More than 57 million people around the world suffering from traumatic brain injury, with 10 million need to hospital admission. In the United States of America around 1.7 million people had experience the concussion every year, making 275.000 patients at hospital and about 52.000 deaths. In the last decade, the incident of concussion increased significantly resulting economic impact to the healthcare sector around more than 15 billion regarding the medical treatment and hospitalization cost and the expenses of lost productivity. It is estimated that concussion related to sport and physical activities is most common to occur in young children due to

their heads are disproportionately large compared to their bodies. The second reason for concussion in young children is football sport where more than 250,000 of children in USA experienced the concussion annually (Kimblor et al. 2012).

### **Required patient data to detect/diagnose/manage concussion**

Concussion detection and management need precise recognition of patient's previous exposure history of concussion and their family medical history too. Patient baseline concussion test is helpful to measure reaction time, memory, speed of mental functioning and decision making processing, recording all these data of each participant over the sport season. Performing this test again in case of concussion presence to establish some comparative scores of studies before and after the injury.

A landmark study achieved by Levin and his team showed that neurophysiological (NP) assessment of concussion in sport designed the foundation of current management system of concussion. Where the recovered concussion participants were examined by neurophysiological (NP) test battery paper pencil tasks showed a significant decrease in neurocognitive functioning after injury had occurred compared with first baseline test (Levin et al. 1989).

The application of neurophysiological examination contains a clinical data and valuable information in concussion assessment. Evaluation of concussion based on neurophysiological indicators including cranial nerve, visual acuity monitoring, muscles strength and reflexes and test balance. Visual activity screening involves the assessment of pupil's response and eye movement to detect any abnormality of eye response or sudden change in visual field. Balance test system is beneficial tool of neurophysiological measurement to assist acute postural stability deficits, brain functioning and valid and reliable addition; certainly, when the symptoms show balance irregularities. Indeed, Balance Error Scoring System (BESS) is commonly used simple technique to evaluate athletes balance capability after brain injury to make decision for play return. More advanced test that can be performed to evaluate balance abnormality is Sensory Organization Test (SOT) by quantifying sways of patient while standing in fixed point using six conditions to identify balance disorder, three of six conditions are related to postural control: somatosensory, visual, and vestibular. SOT can detect balance abnormality during 30 days after injury comparing with 3 days for BESS.

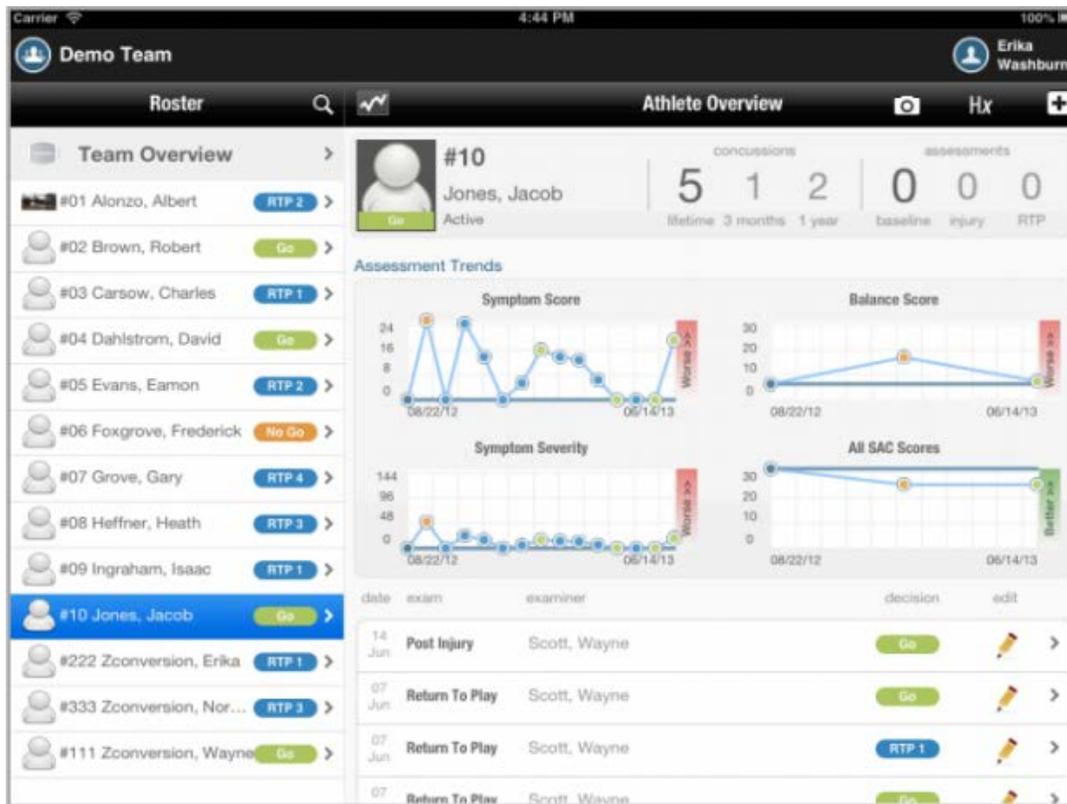
In addition to that, several types of electrophysiological recording methods such as evoked response potential can provide significant clinical information about short and long term of concussion regarding the visual abnormality symptoms (Pillai & Gittinger 2016). Concussion is frequently associated with abnormalities of saccades (Molloy et al. 2017) demonstrated that King-Devick test as rapid visual valuable measure that can be used on sidelines by nonmedical personnel, including parents of youth athletes to improve the potential of concussion detection in sport. Other studies showed the impact of computerized cognitive evaluation test and batteries based test offering a solution for practical problem. (Collie et al. 2001) presented the role of Computerized test designed primary to investigate patients with neurological and brain lesion while the batteries based test modulated for computer presentation and recording such as Cambridge Neuropsychological Test Automated Battery (CANTAB) (Robbins et al 1994). Also, Cognitive tests are needed to detect deficits result in various brain functions such as Wechsler Digit Span Test, Wechsler Letter Number Sequencing Test and Stroop Color Word Test (Maroon et al. 2000).

More over Fluid biomarkers can be useful to detect mild traumatic brain injury and related conditions, Zetterberg and Blennow conclude that the valuable fluid biomarkers are associated neuronal and blood brain barrier injury and neuroinflammation. The capability of fluid biomarker depends on sampling time to quantify brain damage or concussion should be taken as soon as possible after the injury. While bio indicators fluid for delay effects such as neuroinflammation should reach suitable concentration after days or week after trauma. However, limitation for Fluid biomarkers are still under investigation and improvement to establish reference standards for neuropathology to create the diagnosis (Zetterberg & Blennow et al 2016).

Recently medical imaging system play an important role in clinical assessment and classification of brain abnormality. Typical imaging techniques such as X Ray, Computed Topography or Magnetic Resonance Image are not satisfied enough to prove diagnoses of concussion separately. Therefore, more advance imaging technique based on molecular imaging to investigate brain function via measurement of glucose consumption and metabolism activities shows a promotion outcomes when Positron Emission Tomography (PET) integrate with MRI and diagnostic software may be recommended to examine the changes directly after traumatic brain injury and detect any complications could be occurred (Byrnes et al. 2014).

### **Commercial systems on the market for concussion management**

Integrated concussion examination X2 ICE is a useful smart tool based on tablet device combined with windows and iOS software to manage and evaluate player during sport activities to make a decision about suspected athletes using the principle of comparing base line information with after injury signs. X2 ICE system allow the facility to store and match all examination data with previous collected data for the player. Several examination modules are embedded in the system to support short and long term memory test, balance test, cognitive and baseline matching. Furthermore, X2 ICE system is accessible anytime and anywhere due to the possibility to upload collected data to a cloud (Biosystem X2 ICE 2017).



**Figure 1: Biosys X2 ICE concussion examination system (Biosystem X2 ICE 2017).**

In 2005 researches have demonstrated that measurement of angular and linear acceleration lead to more precise prediction of concussion (Yoganandan et al. 2005). While others were interested to specify the ideal location to position the accelerator sensor, (King et al. 2014) explained the superiority of mouth guard positioning. Therefore, Leading Force impact technology company introduce a digital mouth piece called X2IMPACT Guard to solve the problem with players who are return to play while they are still under high probability of brain traumatic injury. X2IMPACT Guard consider as smart device that can measure and store the impact forces affecting inside the head. All collected data can be send to sideline where X2IMPACT application allow direct access to concussion data including previous medical information of players. The clinical of the team assist the real-time concussion data and make a decision to allow participant to return or no.

Head Impact Telemetry (HIS) system is a unique device to measure and record the acceleration of exposure head in real time. Riddell Insite is a commercial impact response system uses during Americans football games, it is based on five accelerator sensors distributed inside the helmet with decoder and transmitter hardware, and interference software compatible with PC and smart phones to access the impact information. HIS integrated with computational algorithms to process data with wireless transmitter to establish real time continuous monitoring data, transmitted directly to a receptor inform of PC or smart phone to correlate the relation between head acceleration and concussion in sport. Software application support the smart phones and computer to record the participant's history, baseline data, environmental setting and impact threshold.



**Figure 2: Riddell Insite Impact Response System (Riddell 2017)**

### **Ongoing research on devices**

Biodirection company performs researches and studies to investigate world first nanowire biosensing platform for concussion and other types of traumatic brain injury based on rapid detection of biomarkers in blood. Tbit device will be able to detect blood protein bioindicator released in bloodstream immediately after TBI within short time around 90 seconds and low cost. As well as that Tbit is point of care platform providing the ability to be portable detection system for TBI. Biodirection company declared that they are still in the middle of clinical researches to prove data needed to be submitted with Food and Drug Administration (Biodirection 2017).

United states company called BrianScop is granted \$28 million from department of defense to establish a wearable EEG portable machine to detect electrical brain activity via smartphones. The device suggested to use algorithm allowing comprehensive outcomes panels. Clinicians and researchers require to concentrate on developing multi-modular assessment platform that explain deficits inhibiting an individual's physical activity. Studying is ongoing phase to specify suit of measure to deliver the most medical related information.

### **Regulations and guidelines of sport related concussion**

Many researches and studies achieved over several years to establish and develop regulations, strategies and laws that managing the sport activities to ensure prevention or at least reduce the possibility of brain injuries. Rules and guidelines for sport related concussion can be summarized into three main points.

High level of awareness and understanding of concussion by coaches, athletes and team medical staff. Significantly the symptoms and medical indicators pointed to concussion, first aid medical procedures to reduce the effect of injuries and protect patient. Applying a plan of proactive regulation to prevent and reduces the brain injuries. Specialized training and education in parallel with brochure and short reports will increase the recognition of all condition related to sport concussion. Currently, social media and on line training courses are widely speared and accessible all around the world, thus could participate significantly to build the knowledge and awareness (CATT 2017).

The 4<sup>th</sup> International Conference on Concussion in Sport held in Zurich, November 2012 focused on the rules and regulation to decide the return of athletes to play again. The decision should be taken by and certified medical expert after looking for recommended protocol including several medical procedures and test such as cognitive and physical rest is needed to allow for recovery before playing again. Moreover, in case of concussion occurrence, short and simple physical exercises should be applying in the first steps of rehabilitation procedures, then progress to an intermediate and fully practices should be covered under the supervision of specialized medical team. However, the allowance to return to play should be provided with medical clearance (Kimble et al. 2012).

Finally, in many countries around the world parent's acceptance to allow their child to participate are compulsory, also concussion training courses for formal coaches are imposed by law. During the game, it is emergence need to take any player with suspected injury out of the playing area and provide the suitable medical care. Playing rules and laws modified by some countries to prevent, diagnose, and early detect players with suggested concussion, some colleges and sport league adopt additional strategies and policies

including; build up a plane including information needed to call emergency medical centers, and to follow several procedures in case of emergency. As possible as can reduce the contact between players by changing and modifying playing rules and assure the safety equipment as recommended by manufacturers (Institute of Medicine 2013).

### **Connected health for management of concussion**

The management of patients after concussion injuries or people a high risk of suspected to traumatic brain injury faces several limitations and problems. Firstly, lack of specialized clinicians who can work with this situation, due to the fact that most sport facilities are spread widely into the countries with huge number of participants, making it difficult to enroll at least one specialist for each facility. Another problem is the failure of people in certain location such as country side or isolated places to access medical services. Connected health solution could have the ability to solve such problem or reduces the side effects of particular limitations.

Continuous educational system offers a significant opportunity for athletes, coaches, parents and medical staff to update their information with the latest results from researches and studies in the field. Portable and Web education resources such as brochure or online training tools will improve the education and reduce the gap between non-medical person who involved concussion risks. Questioner forms or survey will help involved person to record and report the information when concussion incident by answering several questions related to the place and strength of blow, and addressing symptoms and signs. As a result, if the concussion is suspected, the mobile education tool will order to follow certain recommendations and instructions to deal with concussion temporary until the emergency team arrive. On the other hand, some smart applications allow the user to connected to specialist medical staff who can support the patient situation based on obtained information and provide required instruction and recommendations to guarantee the dealing quality with patient case. This type of application is useful in rural and isolated geographical places (Lee et al. 2014).

Nowadays remote medical sensors and devices are useful to evaluation, diagnoses and management of concussion. (Yoganandan et al. 2005) explore that 47% of athletes are playing without recognition the risk of concussion incident. Therefore, it is recommended to wear safety and protective equipment with novel sensor technology that allow early detection of concussion. A good example of safety tool and remote detection equipment is smart helmet. It contains set of biosensor that detect blow forces. When the detected force exceeds a preset threshold value of force, LEDs and alarm system immediately notify the responsible person via wireless or Bluetooth technology at smart phone as receiver which include an application to detect the possibility of injury automatically based on the transmitted value of force hit the player. It also improves the existing technology by calculating the magnitude of the hit, in order to take instant serious measures, allowing specialist medical staff to explain patient information including patient history, severity of injury, signs and symptoms, etc. this medical expert can also contact the patient remotely to detect the suspected injury and transmits patient data to a central database bank (Veena et al. 2014).

### **Challenges with concussion connected health solution**

There are many interests and challenges regarding using the connected health in the management of concussion. Recognizing and assessment of concussion within player on the field is a challenging procedure and responsibility for the medical care provider. Achieving this task requires rapid assessment according to standard objective evaluation of injury. Specialist medical staff considers as the main point in the management of concussion in the field, consulting education and training is major difficulties for healthcare provider due to the high cost of training and education in this field. More over this desired training and education is time consuming regarding to several related conditions and details that must be covered to achieve certain level of medical support. On the other hand, the connected health care system based on using internet and wireless signal in data transmitting may lead to break the privacy and confidentiality of patient's information.

### **Conclusion**

Finally, telemedicine is a significant tool to manage, detection and diagnose concussion in parallel with smart phones applications and biosensors. Incorporating biosensors with safety equipment and tools in sport lead to early detection of concussion by measuring the hit force or both types of acceleration allowing health care specialist to proceed remotely tests and evaluation of concussion over internet connection or mobile signal allowing to early detect of injury even at isolated places. In addition to that, smart solution and application provide a great opportunity to develop and improve the management and treatment of concussion patients and help clinical to make correct decision of return to play. Consequently, good management, correct decision and early detection of concussion are fundamental for rapid recovery and relieve the effects of concussion.

### **References**

Biodirection, 2017. Tbit Blood Testing Platform. Available at: <http://www.biodirection.com/tbit-platform/>.

Biosystem X2 ICE, 2017. Biosystems X2 ICE-integrated concussion examination. Available at: [www.biosystem.com/Biosystem X2 ICE](http://www.biosystem.com/Biosystem X2 ICE).

Byrnes, K.R. et al., 2014. FDG-PET imaging in mild traumatic brain injury: A critical review. *Frontiers in Neuroenergetics*, 6(JAN). Available at: <http://www.ncbi.nlm.nih.gov/24409143>.

CATT, 2017. The Concussion Awareness Training Tool. Available at: <http://www.cattonline.com/>.

Collie, A., Darby, D.G. & Maruff, P., 2001. Computerised cognitive assessment of athletes with sports related head injury. *British Journal of Sports Medicine*, 35(5), pp.297–302. Available at: <http://www.ncbi.nlm.nih.gov/entrez/11579059>.

Daneshvar, D.H. et al., 2011. Long-Term Consequences: Effects on Normal Development Profile After Concussion. *Physical Medicine and Rehabilitation Clinics of North America*, 22(4), pp.683–700. Available at: doi: 10.1016/j.pmr.2011.08.009.

Institute of Medicine, 2013. Sports-Related Concussions in Youth: Improving the Science, Changing the Culture. *Institute of Medicine Report*, 180(Dc), p.24199265.

Kimble, D.E., Murphy, M. & Dhandapani, K.M., 2012. Concussion and the Adolescent Athlete. *Journal of Neuroscience Nursing*, 43(6), pp.286–290. Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3818791>.

King, D. et al., 2014. Instrumented Mouthguard Acceleration Analyses for Head Impacts in Amateur Rugby Union Players Over a Season of Matches. *Am J Sports Med*, ePub(ePub), p.ePub-ePub. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/25535096>.

Lee, H. et al., 2014. Smartphone and tablet apps for concussion road warriors (team clinicians): a systematic review for practical users. *British journal of sports medicine*, pp.1–2. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/24668048>.

Levin, H.S., Eisenberg, H.M. & Benton, A.L., 1989. *Mild head injury*. Available at: <http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=1989-97694-000&site=ehost-live>.

Maroon, J.C. et al., 2000. Cerebral concussion in athletes: Evaluation and neuropsychological testing. *Journal of Neurosurgery*, 47(3), pp.659–672.

McCorry, P. et al., 2009. Consensus Statement on Concussion in Sport – The Third International Conference on Concussion in Sport Held in Zurich, November 2008. *The Physician and Sportsmedicine*, 37(2), pp.141–159. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/19627927>.

Molloy, J.H., Murphy, I. & Gissane, C., 2017. The King–Devick (K–D) test and concussion diagnosis in semi-professional rugby union players. *Journal of Science and Medicine in Sport*, pp.9–12. Available at: <https://www.ncbi.nlm.nih.gov/pubmed/28258820>.

Pillai, C. & Gittinger, J.W., 2016. Vision testing in the evaluation of concussion. *Seminars in Ophthalmology*, 32(1), pp.1–9. Available at: <http://dx.doi.org/10.1080/08820538.2016.1228412>.

Riddell, 2017. Riddell Insite Impact Response System. Available at: <http://www.riddell.com/InSite>.

Robbins et al, T., 1994. CAMBRIDGE NEUROPSYCHOLOGICAL TEST AUTOMATED BATTERY (CANTAB): UTILITY AND VALIDATION. *IEEE Xplore Digital Library*, INSPEC Acc. Available at:  
<http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=369607>.

Veena, D.K. et al., 2014. A compact sensor system for concussion mitigation in helmets - A concept prototype. *Proceedings of 2014 International Conference on Contemporary Computing and Informatics, IC3I 2014*, pp.363–366. Available at:  
<http://ieeexplore.ieee.org/7005967>.

Yoganandan, N. et al., 2005. Biomechanical Aspects of Blunt and Penetrating Head Injuries. *IUTAM Symposium on Impact Biomechanics: From Fundamental Insights to Applications*, pp.173–184. Available at: [http://dx.doi.org/10.1007/1-4020-3796-1\\_18](http://dx.doi.org/10.1007/1-4020-3796-1_18).

Zetterberg, H. & Blennow et al, K., 2016. Fluid biomarkers for mild traumatic brain injury and related conditions. *Nature Reviews Neurology*, 12(10), pp.563–574. Available at: <http://www.nature.com/doi/10.1038/nrneurol.2016.127>.