Importance of Chewing Simulators in the Difference of Test Results of Dental Materials. Systematic Review

Abstract

Objectives:

With new dental materials constantly being launched on the market, the number of researches on the properties of dental materials have increased substantially in the past few years. However different results about physical properties of the same material are frequently found in the literature. In an endeavor to elucidate the cause(s) of these disparate results, a review of the literature published in the last five years was conducted, to investigate whether these differences are due to the testing machines - also called chewing simulators – used in the studies.

Data:

We searched for data of indicators of test accuracy, maintenance of test parameters during all experiments, reproducibility of test and standards in the articles, or in the manufacturers' sites.

Sources:

The database searched was CAPES PORTAL (http://www-periodicos-capes-gov-br.ez27.periodicos.capes.gov.br)

Study Selection:

In the search, the following keywords were used: "bite force" AND "simulator", "chewing simulator" and "mastication simulator", and the publication filter date of "January 1, 2016". As a result, 100 articles were selected and recovered in order of appearance by using the filter "relevance".

Conclusion:

based on the data obtained in this review, the disparate results of experiments with dental materials appeared to be more related to the test conditions rather than with the testing machines.

Keywords: Testing machines, chewing simulators, dental material, pre-clinical tests, systematic review.

1. Introduction

Since the end of the 19th century, there has been concern in dentistry about the progress of science and new technologies for improvement in clinical practice [1]. The number of materials and manufacturing methodologies have increased considerably in recent years. Knowledge of human bite force and the physical properties of restorative materials and their biocompatibility is fundamental in the practice of dentistry, in order to perform the required anatomical and functional restorations of the stomatognathic system (SS).

In the 19th century, Black [2] measured the bite force to understand the characteristics of the human tooth in relation to the pathologies that affected it and to obtain information in order establiss the physical properties necessary for a restorative material.

Correct chewing with an ideal bite force is a most important factor in the morpho-functional maintenance of the SS and brain health (brain-stomatognathic axis), since chewing stimulates the release of neurotransmitters such as serotonin, dopamine and mineralocorticoids in the central nervous system (CNS). These neurotransmitters contribute to well-being, protect against autonomic cardiac arrhythmias, improve the learning condition and slow brain aging [3,4,5,6,7,8,9,10]. Clearly, inadequate restorative procedures and/or materials can compromise these benefits provided by mastication.

Before testing a material in the mouth, it has to undergo a preclinical test to find out its resistance to fatigue, wear/aging, fracture and effect on antagonist teeth, among other properties. This is why the application of specific loads to this material is necessary to simulate the conditions of the SS by means of a testing machine. Another use of testing machines is to study the effects of chewing on food bolus [11,12]. There are simulators that serve both purposes, such as those made by SD Mechatronik (Mechatronik GMBH, Feldkirchen-Westerham) [13].

Due to the insertion of the CAD/CAM process of obtaining restorations and implants in dentistry, and the increasing numbers of polymers that can be used in this process, testing machines are fundamental, although they are not always used[14].

According to Heintze [14] some restorative materials have been for sale on the market for a long time without having undergone pre-clinical tests, especially metal porcelains, thereby placing patients at risk. Furthermore, Yiamaz et al [15] reported that in the last century, none of the wear test machines used in dentistry were included in an international standard. In 2001, standards were established for testing the wear resistance of dental materials in two- and three-body wear machines in accordance with the International Organization for Standardization (ISO) technical specifications [15].

In 2006, Heintze [16] conducted a study similar to the present review, and at the time, reported that only the MTS simulators (MTS Corp., Minneapolis, MN, USA) were qualified for in vitro wear testing. According to the author, the force exerted by the actuator was controlled and regulated throughout the test only in the MTS simulators. The weak reproducibility of the tests would be the explanation for the great variation of results found at the time.

The load simulators are divided into three major groups: static load simulators, dynamic load simulators and mixed simulators that can generate static and dynamic loads. Dynamic load simulators provide more data such as tension, bend, durability, high cycle fatigue, low cycle fatigue, compression, creep, fatigue crack growth, fracture toughness [17] than static load simulators, however, they have a higher cost and are less accessible to research (fewer job places on the bench) [14].

In this database search, the first simulator found in the literature was conceived by Head [18], who used a dry skull to determine the force necessary for crushing food during human chewing, with the purpose of using the information for the development of restorative materials. He performed the test by placing the skull upside down, then he attached a bucket to its jaw by means of wires, and placed weights in it(the bucket) to find out what pressure was needed for crushing the food.

The aim of this article was to review the literature in the last 5 years in order to evaluate the characteristics of the simulators used in the literature, based on the technical data found in the respective websites and/or in the published studies of customized simulators, to find out about the state of the art of simulators, their accuracy during the tests and the reproducibility of the tests.

2. Methodology

A search was conducted in two data bases, both accessed on 27/06/2020. with the following keywords: "bite force" AND "simulator", "chewing simulator" and "mastication simulator". In PUBMED (https://pubmed.ncbi.nlm.nih.gov/), using the date of publication filter “5 years” , 204 articles were found; and in CAPES PORTAL (http://www-periodicos-capes-gov-br.ez27.periodicos.capes.gov.br), using the date of publication filter “January 1, 2016” , 403 articles were found. We opted to use the data from the CAPES PORTAL data base. Out of the 403 articles found in the search, 100 articles were selected and recovered in order of appearance, by using the search parameter filter "relevance".

Three articles were excluded due to the methodology applied. They used no testing machine, only Finite Element Method Analysis [19,20,21].

In the other 97 articles, two distinct groups of chewing simulators were found: those manufactured by industries and for sale (from now on, this type will be referred to as commercialized simulators) and those developed by universities, research centers, research groups (from now on, these will be referred to as customized simulators). In the former group the technical information and standards were searched on the manufacturer's website. In the customized group, technical information was searched in the paper itself, or in another paper if this type were cited.

2.1 Testing machines for food study

Among the 100 studies recovered, 4 of them [11,12,13, 22] used the chewing simulator to study substances released while the food bolus was being chewed. Mohammadi, Ehsani and Bakhoda [13] used a Cs simulator from SD Mechatronicks that will be evaluated later when evaluating the simulators for the study of property of restorative materials.

Mennis-Henrique et al [11]; Tarrega et al [12] used the customized simulator developed by Salles et al [23]. This simulator consisted of an active cell, where the chewing process was performed, an electronic control box and a computer to monitor and adjust each parameter. The active cell, composed of a movable jaw and a fixed jaw; both jaws were ring-shaped cylinders fitted with molars made of polyetheretherketone (PEEK) cylinders, and a tongue, exerting a force 30 dekanewtons, a shear force of 35 dekanewtons at an angle with value corresponding to 1/8 of the tooth. Although we had no access to more technical information, the data described in the studies led us to believe that it was an efficient simulator that would allow test reproducibility and accuracy.

Peyron et al [22] used the AM2 chewing simulator that was validated by Woda et al [24]. This simulator had two discs, one fixed, corresponding to the maxilla, and one mobile, corresponding to the mandible. The shape of the discs differed from human dental anatomy, but were similar to contact surfaces at work as in human chewing. According to the authors, the food bolus resulting from crushing in the simulator was statistically equal to the food bolus crushed by human chewing with regard to particle size.

2.2 Chewing simulators for testing physical properties of materials

2.2.1 Customized

The customized simulators were used in 11 of the articles recovered. The chewing simulator developed by the University of Zurich was used by Ender et al [25], Zhi, Bortoloto and Krejci [26] for fatigue testing. According to the authors, it generated a load of 49 N, and the frequency and numbers of repetitions could be adjusted. In addition, it allowed a thermal cycling process operating between 5 and 50 degrees Celsius, with precision, frequency and load monitoring and controlling devices or system reported, but no standard was reported.

Singhatanadgit, Junkaew, Singhatanadgid [27] developed a chewing simulator for in vitro measurement of unidirectional and bidirectional loads. Systems for monitoring and controlling the frequency, precision and load were reported, but no standard was reported.

Gundugollu et al [28] developed a wear simulator consisting of two aluminum discs, one fixed bottom, and one upper rotating at 10 RPM driven by a Johnson engine with a capacity of 5 kg. According to the authors, the contact geometry was representative of masticatory function. They did not report any electronic process monitoring and controlling devices of precision and load, and any standard.

Guo et al [29] used a customized simulator developed by the Fourth Military Medical University. They used spheres as antagonists to investigate the tribological response of dental crowns to cyclic loads. After heat treatment, the spheres made of stainless steel were similar to the natural enamel. The authors describe mechanisms for monitoring and controlling the process (precison, frequency, and load) in order to maintain the same conditions during the test and its reproducibility. No standard was reported.

Ziprrich et al [30] used the Frankfurt chewing simulator that was designed and built specifically to test implant connections. A two-dimensional load could be applied, simulating the chewing forces as far as possible. Two actuators driven by Lorenz's force were used for load generation at a 90 degree angle. The strength and time variables were adjustable. The force produced by the actuators could be generated in arbitrary directions between +90º and -90º in relation to the long axis of the implant and ranged from zero to 300 N. Actuators were controlled by an electronic amplifier, which in turn, were controlled by the labview graphics programming system® [31]. From the authors' description, this simulator was a machine that allowed the same conditions (precison, frequency and load) to be maintained throughout the test, and reproducibility of the test [30,31].

Dayan et al [32] used the chewing simulator developed by the University of Selcuk, Research Laboratory Centre, Konya, Turkey). The simulation chambers were filled with artificial saliva that was maintained at 37º C throughout the test period and the occlusal contacts occurred under simulated physiological conditions. The dynamic load was obtained with a pin-on-block design with 0.5 mm glides at a frequency of 1.2 Hz with a constant load of 50 N per 20,000 cycles. No standard was reported.

Tahir et al [33] presented a chewing simulator that was developed to aid the placement of implants. It had a robotic chewing system with 6 degrees of freedom, with hydraulic actuators that replicated the action of the jaw in order to replicate the forces occurring in normal chewing. The authors reported a control system to maintain constant hydraulic pressure in the actuators. Test accuracy was guaranteed because the kinematic structure was a redundant robot arm - SCARA (Selective Compliance Assembly Robot Arm). Industrial grade systems have also been developed to conduct monotonic and cyclic tests, which are predominately uniaxial compression and tensile testers. These systems have also been used for (ISO) 14801 standardization testing.

Ip et al [34] developed a bite force simulator composed of pistons supported by a customized impression of the individual's skull obtained by 3D printing. Muscle loads were generated by proportional pressure controllers (PPC5C; MAC Valves, Wixom, MI), operated by LabVIEW software by means of an analog voltage controller (National Instruments, Austin, TX), those devices control experiment conditions which guarantee accuracy and reproducibility, but no standard was reported.

Yilmaz et al [35], Yiamaz et al [36] idealized and produced a biaxial mastication simulator that exerted a 50 N load on the vertical axis and horizontal slide of 0.7 mm when the simulator came into touch with the studied specimen. This was controlled by magnetic sensors, so that after (touching the specimen) the load returned to the beginning allowing the load to be exerted at the same point, and accurately reported the point of force application, however, the authors did not report any frequency controlling systems or devices, nor standards.

2.2.2 Commercialized Simulators (for sale)

Passia, Ghazal and Kern [37], Yagizi, Kern and Chaar [38] used a computer-controlled biaxial chewing simulator; and Swain et al [39] used a universal fatigue simulator; Al Akhali et al [40], Asahhaf et al [41], and Yagizi et al [42] used the artificial aging machine simulating 5 years of use; all these items of equipment were manufactured by Willytec (Feldkirchen-Westerham, Germany). Willytec was the previous name of SD Mechatroniks[43].

Preis et al [44], Nalmann et al [45], Preis et al [46], Kammermeier et al [47], von Stein-Lausnitz et al [48], Rosentritt et al [49] used the chewing simulator manufactured by EGO (Regensburg, Germany) with Willytec technology. This simulator allowed thermal cycling, operating between 5º and 55º C and testing with vertical and horizontal movements.. Apart from stating the Willytec technology, there was no report on the manufacturer's website, about standards used for the manufacture of simulators, or of devices or monitoring and control systems [50].

SD Mechatronik chewing simulators (Mechatronik GMBH, Feldkirchen-Westerham, Germany) CS 4.2 have been indicated for determination of the resistance to composite wear, fracture resistance of crowns, bridges and implants, and simulation of bruxism for interocclusal plate testing. According to the manufacturer they have a high degree of reproducibility of results because they allow identical kinematic conditions in each species placed in the test chambers. Model CS 4.8 simulates various masticatory movements to test implants, bridges, crowns, composites and jaw models. It performs the complete masticatory cycle through linear motion along 2 axes. It simulates chewing frequency up to 5 Hz, simulates bruxism for interocclusal plate testing, and can offer real-time wear analysis. The two models provide thermal cycling operating between 5 and 55 degrees Celsius[51] and were used by Choi et al [52]; Koutousis, Gadalla, Lundgren [53]; Ladetski et al [54]; Yoon et al [55]; Askar et al [56], Elsayed et al [57]; Heintze et al [14]; Im et al [58]; Vafaee et al [59]; D'Arcangelo et al [60]; Elshyab et al [61]; Garoushi, Vallittu, Lassila [62]; Irmak et al [63]; Kewekordes, Wille, Kern [64]; Lehmensiek et al [65]; Mohammadi, Ehsani, Bakhoda [13]; Nawafleh et al [66]; Roulet, Abdulhameed, Shen [67]; Santos et al [68]; Sarikaya, Hayran [69]; Qasim, El-Masoud, Laban [70]; Zierden et al [71]; Agustin-Panadero et al [72]; Atsü et al [73]; Lassila et al [74]; Baumgart et al [75]; Dayan, Muncu [76]; Elkabbany, Kern, Elkhadem [77]; Lutz et al [78]; Riedel et al [79]; Sorrentino et al [80]; Hsu et al [81]; Zildan et al [82].

Stawarczyk et al [83] reported the use of CS 4.10 but the model was not found on the site. These simulators were all produced with Willytec technology. According to the site the simulators comply with the following standards: ISO 14801 :2017, ISO 6872: 2019, ISO 10477: 2017 and ISO / TS 14569 [51].

Instron (INSTRON, Norwood, MA, USA) manufactures several universal simulators that have proved to be efficient in pre-clinical tests, each related to the type of material tested. Huang, Chen, Lin [84] used the E3000 model. Ladetski et al [54] used model 4411 for static load testing. Mahmood et al [85] the Instron 4465, Pinto et al [86] the Instron 8501, Choi et al [87] used model 8871, Pedrollo Lise et al [88] used Instron 5848 MicroTester that tested laminates and bonding force. Allamari et al [89] reported the use of the universal test machine, capable of performing rupture tests at high temperatures, while Clausson et al [90] used the EMIC DL 2000 for determining the strength of materials in the following types of tests: tensile, compression, bending, bending, shear, pullout, delamination, adhesion, inlay, etc.; that is to say, all classes of destructive mechanical testing. This equipment, which performs rupture tests at high temperatures, is supplied with the Bluehill testing software. Sagsoz and Sagsoz [91] used the Instron/EMIC 3344 for fracture testing. Instron test machines comply with ISO 6892-2, EN 10002-5, ASTM E21 standards. [92]

Zwick/Roell (Ulm, Germany) offers several dynamic simulators, among which the choice depends on the properties of the material to be tested and the desired load. All models listed below were used for preclinical testing. According to the manufacturer all models have test control II, software that allows a very precise positioning of the tested part, measurement and test reproducibility. The Z050 model is indicated for testing fatigue, indentation hardness and compression stress. All tests are performed in 3 phases: in the first, the thickness and hardness of indentation is measured, in the second, a fatigue load between 8.00 and 150,000 cycles is given, depending on the material tested and the next stage tests the reduction in thickness and the load for loss of interdentation; The Z 005 model offers compression testing up to 5 kN, and thermal testing; Model Z 1445 offers pressure of up to 10 kN indicated for fracture testing in flexible polymers. The Z010 model offers pressure of up to 10 kN, ZwickiLine 2.5 kN offers pressure of up to 2.5 kN [17]. (Nazari et al [93]; Stawarczyk et al [94]; Habibzadeh et al [95]; Sieper, Wille and Kern [96]; Alkharrat et al [97]; Elsayed et al [98] Obermeier et al [99]; Bishit et al [100], Jagodin et al [101]; kelch et al [102]; Nouhl et al [103], von Stein-lausnitz [48]; angermair [104]; Bunner and özcan [105]; Ioannidis et al [106]; Winter et al [107]). Zwick/Roell manufacturing test machines comply with ISO 9001 and 14001 standards [17].

Fathy and Swain [108] used the Robota Company chewing simulator (Alexandria, Egypt) equipped with servo-oriented steering system motors for horizontal and vertical movements, adjustment of distance of movement, integrated with thermal cycling and adjustment of the level of the active tip for accurate positioning [109].

Mieda et al [110] used the ANSYS program for finite element method study and Shimadzu's AG-10kNXplus universal test machine (Kyoto, Japan) for static and dynamic load testing. The device has trapezium x processing software that ensures reproducibility in all tests regarding the intensity and vector of load application and complies with ISO 6892: 2016 (JIS Z 2241:2011) standards [111].

Sedrez-Porto et al [112] and Silva et al [113] tested the fatigue of direct intracoronal restorations using the Biocycle V2 pneumatic chewing simulator from Biopdi (São Carlos, Brazil). This equipment performs mechanical fatigue tests that closely simulate the tests of the conditions found in the human mouth, and improves the in vitro study research methods that simulate human mastication. Compression or impact tests can be performed with forces that can range between 0 and 200kgf. Because it is powered by compressed air, it can reach frequencies of up to 5 Hz, without losing efficiency and up to 10 Hz in specific cases. It also has a sliding system for tests that best simulate masticatory movement, such as bruxism tests. It is provided with Software for making adjustments, configurations, acquisition, analysis and reporting of mechanical tests and complies with the NBR ABNT, ISO, ASTM, and DIN standards [114]

For dynamic fatigue tests, Katonaa and Eckert [115] and Kim et al [116] successfully used dynamic MTS Bionix 858 (MTS Corp., Minneapolis, MN, USA). Zhang et al [117] used the MTS Land-mark 370.10 model. MTS test machines feature hydraulic Servo innovations, versatile flextest control, and application software that provides high accuracy and reproducibility in high fidelity static and dynamic testing, and different types of stress, compression and fatigue tests and comparisons. All comply with ASTM D3039 standards, ASTM D2344, ASTM D790, ASTM D3518, ASTM D5023, ASTM D5024, ASTM D5026, ASTM D5418, ASTM D5992, ASTM D6272, ASTM D7028, ASTM E21, ASTM E290, ASTM E517, ASTM E646, ASTM E8-E8M, ASTM E9, ISO 10113, ISO 10275, ISO 14125, ISO 6892-1, ISO 6892-2, ISO 7438, ISO 14129, ISO 527-4, ISO 527-5, ISO 6721-4, ISO 6721-12, EN 2561 , EN 2562, EN 2597, EN 2746, EN 6031[118].

Bankoğlu Güngör, Karakoca Nemli [119]; Bankoğlu Güngör et al [120]; Rajic et al [121]; Sagsoz, Polat Sagsoz [122]; Sen, Us [123]; Benli et al [124] used the Mastication Simulator MOD (Esetron Smart Robotechnologies, Ankara, Turkey) a dynamic simulator that had a user-friendly interface and allowed remote monitoring during testing that allowed adjustment of all test parameters, including temperature. This equipment can be used for mono or biaxial tests and allows reproducibility of the tests. It is ideal for testing the physical properties of restorative materials or the study of impact of any event on dentition. Esetron test machines comply with ISO 9,100 ISO 12,100 [125].

Kim et al [116] used ADL-Force 5 (Advanced Mechanical Technology Inc., Watertown, MA, USA) for static mechanical fatigue testing. Force 5 could replicate the loading and full amplitude of multi-axis motion associated with daily activities. Four servo-hydraulic actuators control the movement of the mobile base through an electric motor. According to the manufacturer the test machine complies with the following standards: ISO-14242-1, ASTM-WK451, ASTM-F1612-95, ISO/DIS-7206-4, ISO-14243-1, ISO-14243-3, ASTM- F1715-00, ASTM-F1800-04, ASTM-F1223-05, ASTM-F2423-05, ISO/DIS-12189, ISO/DIS-18192-1, and ASTM-F1717-04 [126].

He et al [127] used a model LRX and D'Addazio et al [128] a model LR30K from Lloyd Instruments Ltd.,(Fareham, England), which complies with the ASTM D790, ISO 178, BS 2782 standards for flexural polymer testing. According to the technical data this equipment provide high accuracy and reproducibility. For flexural testing, the machines can compensate for the deflection of the equipment [129].

3. Results

All the data presented and discussed here from now on was based on the information reported in the articles. It is important to bear in mind that the testing machines may have had the systems or devices we were looking for, but since their presence was not reported in the articles we will consider that they were absent.

In relation to chewing simulators for the research of chewing effect on the food bolus found in 4 studies, 1 of them used a commercial chewing simulator from SD Mechatroniks manufactured in compliance with standards and with control and monitoring devices [13]. In two studies, the same simulator was used [11,12] and did not report any monitoring and control devices or systems. In one of the studies, a chewing simulator was used, and although there was no report of devices or monitoring and control systems, the equipment was validated with regard to the grinding capacity of the food bolus [22, 24].

Relative to the customized simulators for research of the physical properties of materials, 11 studies were found, yet only one [33] reported standards for the simulator.

The data* about the customized simulators used by Ender et al [25] and Zhi et al [26] developed by the university of Zurich, were* first published in 1999 by Kerjci et al [130], we could not recover complete text, but in the abstract they reported that it was a computer controlled simulator, so we inferred that it had a system for monitoring and controlling the experiment.

All the customized simulators were able to produce the experimental conditions of the commercialized types. When we considered the control systems or devices to maintain the same conditions throughout the entire experiment, eight studies reported precision, frequency and load control system for the simulator [25,26,27,29,30,31,32,33,34]. Only one article did not report precision or load control systems [28], and two did not report frequency control [35,36]. Table 1.

Table 1 Information about accuracy and reproducibility of customized simulators reported on the articles

Reference	Precision control	Frequency control	Load control	Standard
[25]	Yes	Yes	Yes	No
[26]	Yes	Yes	Yes	No
[27]	Yes	Yes	Yes	No

[28]	No	Yes	No	No
[29]	Yes	Yes	Yes	No
[30]	Yes	Yes	Yes	No
[32]	Yes	Yes	Yes	No
[33]	Yes	Yes	Yes	ISO 14801
[34]	Yes	Yes	Yes	No
[35][36]	Yes	No	Yes	No

Among the 82 studies recovered that used chewing commercialized simulators to study the physical properties of materials, 4 used 2 distinct simulators for static and dynamic load [48,54, 91,116]

In the present review were found commercialized simulators manufactured by Willytec, Mechatroniks GmbH, Instron, MTS Corp, Robota Company, eGo Kältesysteme GmbH, Zwick/Roell, Shimadzu, Biopdi, Esetron Smart Robotechnologies, Loyd and ADL (Advanced Mechanical Technology).

The most frequently found types were those with Willytec technology (Willytec, SD Mechatroniks, eGo Kältresysteme). As regards manufacturers, SD Mechatroniks simulators were the type most used. Table 2.

Only two manufacturers (eGo Kältersysteme and Robota company) did not show any references on their respective sites, with regard to technical standards for construction of the simulators. Since eGo Kältesysteme used Willytech technology we assumed that the simulators would comply with technical standards.

Only the eGo Kältesysteme did not mention monitoring and controlling system that would guarantee reproducibility and accuracy of the tests, since they used Willytec technology, we assumed that the simulators would have monitoring and controlling systems.

Based on the data obtained in this review we believe the testing machines themselves are not responsible for the disparate results found in the literature about physical properties of materials used for restorative purposes. This finding is in accordance with study of Sen & Us [123], who indicated that in addition to the test machine, test conditions with the number of fatigue cycles, load applied, simulated bone level, superstructure design, load indenter specifications, hydrothermal aging and load application angle were factors that could influence test results; therefore, tests conditions are more likely to influence the results nowadays, than the testing machines.

Table 2 Information obtained on the websites of manufacturers

Manufacturer as reported	Number of articles	Controlling systems	Technical standards
Willytec	6	Yes	Yes**
Mechatroniks GmbH	33	Yes	ISO 14801: 2017, 6872: 2019, 10477: 2017 & ISO / TS 14569
Instron	9	Yes	ISO 6892-2, EN 10002-5, ASTM E21
MTS Corp	3	Yes	ASTM D3039, D2344, D790, D3518, D5023, D5024, D5026, D5418, D5992, D6272, D7028, E21, E290, E517, E646, E8-E8M, E9, ISO 10113, 10275, 14125, 6892-1, 6892-2, 7438, 14129, 527-4, 527-5, 6721-4, 6721-12, EN 2561, 2562, 2597, 2746, 6031
eGo Kältersysteme GmbH	6	Yes**	Yes**
Lloyd Instruments Ltd	2	Yes	ASTM D790, ISO 178, BS 2782
Advanced Mechanical Technology Inc	1	Yes	ISO- 14242-1, ASTM-WK451, F1612-95, ISO/DIS-7206-4, 18192-1, ISO-14243-1, 14243-3, ASTM-F1715-00, F1800-04, F1223-05, F2423-05, ISO/DIS-12189, F1717-04
Esetron Smart Robotechnologies	4	Yes	ISO 9.100 ISO 12.100
Shimadzu	1	Yes	ISO 6892:2016 (JIS Z 2241:2011)
Biopdi	2	Yes	NBR ABNT, ISO, ASTM, DIN*
Robota Company	1	Yes	No
Zwick/Roell	16	Yes	ISO 9001 & 14001

* no report of standard number
** since Willytech and Mechatroniks technology are the same test machine, and Ego Kältersysteme uses Willytech technology, although no information about the monitoring system was found on the website, they will be treated as the Mechatroniks simulator, with regard to these items.

When taking into consideration the ISO standards (https://www.iso.org/home.html), ASTM standards (https://www.astm.org/), European standards (https://www.en-standard.eu/), British standards (https://www.bsigroup.com/en-GB/) and Japanese Standards (https://webdesk.jsa.or.jp/) used by the test machine manufacturers, it was clear that the testing machines were capable of performing the tests required for dental materials. The standards comprised 23 different physical tests, with 17 different types of materials

Conclusion

Based on the simulators studied in this review, it could be concluded that:

- The testing machines used for the study of food properties, reported systems for controlling and monitoring the experiment
- The majority of the customized testing machine appeared to be able to maintain and reproduce the experimental conditions throughout the experimental period.
- The commercialized test machines found in this review had systems that guaranteed the accuracy and reproducibility of the experiments
- Almost all commercialized test machine manufacturers (except one) in this review showed standards on the website, which guaranteed the accuracy and reproducibility of the experiments.
- Based on the data acquired in this study, it would appear that differences in test results of physical properties of materials could be more related to the parameters established for the test than to the accuracy and reproducibility of the test machines, or the correct choice of the test machine for the investigation.

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