Accuracy of digital appliances for use in dentistry for dummies

The world’s largest dental fair, the Internationale Dental-Schau (IDS) promoted as “The Greatest Dental Show on Earth” ended just a few days ago in Cologne. The claim is probably true since this year, there were 155,000 visitors over the 5 days that scrambled amongst the 2,305 exhibitors. As expected, the array of new equipment, tools, materials, and appliances on display was daunting. A conspicuous element was the presence of numerous digital hardware and software technologies. The consequences of digitalization to compress work time and/or replace manual labor-intensive tasks of the dental professionals has until now predominantly impacted dental technicians. Personally, I am still sceptical that replacing highly skilled craftspersons in dental technology with less competent workhands trained only to run a particular CAD software or operate a particular CAM device is positive (Jokstad, 2016). A general belief is that digital tools assure better patient care, including the notion that dental devices manufactured by machines are of equal or even higher quality than those made by human hands. We can therefore expect that new digital technologies will likely continue to be launched at events like IDS.

Being a prosthodontist, I spent much time at the IDS this year trying to obtain facts about the new products within oral rehabilitation that enable the assimilation of data from tomography technologies with surface rendering from intraoral and extraoral scanning. Some of these products can even integrate physiological and jaw tracking data for CAD–CAM manufacturing of dental devices (Jokstad, 2017). However, this editorial is not about innovative digital technologies, but rather about the perplexing realization that for many, the three terms accuracy, precision, and trueness seem to be incomprehensible. It was even more discouraging to solicit information about repeatability and reproducibility of new digital products, although I recognize that their interpretation in a statistical context differ from our everyday use of the terms. Admittedly, because the IDS draws such a large crowd, every exhibitor booth was staffed for the occasion with salespersons, assistants, technicians, clinicians, perhaps the occasional engineer or crowd of dental students and likely including several relatives too. Any engineer will easily be able to explain how accuracy is the sum of trueness and precision, and specifically in Cologne, Germany, a local engineer would explain the same with the terms “Genauigkeit,” “Richtigkeit,” and “Präzision.”

Nevertheless, I believe that we as dental professionals owe it to our patients to identify the elements of accuracy of new digital tools developed for diagnostic purposes or for fabricating dental devices with CAD–CAM machinery. A start is simply to distinguishing between the three terms. I hope that the reader may understand these differences by visualizing the scenario in the following narrative.

Imagine that you have obtained a permanent parking space for your car. Your spot is between two other cars in an area that is confined by concrete walls. Thirty centimeters has been allotted on each side of the cars for opening doors. Both your neighbors park their cars consistently on the same spot every time, meaning that their parking is “precise”. A few occasional deviations from their spot occur, and these represent what are termed “random errors.” Unfortunately, you are a bit annoyed because even if their parking is precise, the two cars are consistently positioned, respectively, 35 cm away and 40 cm away from their adjacent concrete walls, leaving only 20 and 25 cm for you. (Nobody really wants to bump their car doors into concrete walls and some have this inclination stronger than others.). Hence, although their parking “precision” is excellent, you are unimpressed. Neither should you as a dental professional be satisfied if a sales representative can inform you only about the “precision” of a new digital appliance, while ignoring its “trueness.” Incidentally, two terms often used in context with a measurement of precision are “repeatability” and “reproducibility.” They describe, respectively, the precision measured under similar conditions, (e.g., parking on sunny days), and the precision measured under different conditions (e.g., parking on sunny days vs. days with foggy car windows). One may conceive clinical scenarios in dentistry. It is important to recognize that any digital appliance requires both inherent excellent “repeatability” as well as “reproducibility.” For those who remember some of their statistics, think of measuring intravariability and intervariability.

Going back to the narrative, occasionally, some unfamiliar car is parked in the adjacent parking spaces, but for whatever reason they never seem to be parked correctly in their spots. Sometimes, an adjacent car is positioned close to the concrete wall and at other times perhaps up to 50 cm away from its intentional spot. You decide on a particularly bad day when both adjacent cars block you from entering your own, to document with photographs their sloppy parking practices. However, after having compiled enough photographs, you are amazed to discover that in the long run, the average distances of the spaces between the wall-car-car-wall equals to 30-30-30-30 cm (remember the term “regression towards the mean in statistics”?). In other words, the “trueness” of the constantly sloppy parking is excellent, which becomes more and more obvious the more photographs you accumulate. (I will spare the readers for a lengthy explanation why this is expected as based on statistical theories.). More importantly is the inference that “trueness” as a numerical entity is inadequate for making a qualified estimate of “accuracy.” Hence, as a dental professional, you should not be impressed by sales representatives who can provide to you only the trueness of their digital appliance.
While precision and trueness differ, a combination of the two indicates accuracy. In the figure, consider which of the four hypothetical CAD–CAM concepts that you hope your dentist or dental technician team have purchased if you are in need of a single-implant crown for yourself. In this example, trueness is set relative to the value 0 μm and the clinically acceptable to <100 μm (booth numbers are debatable, but that is for another discussion); Figure 1.

From left to right on the figure, one discerns that the average fit of dental devices made by the four different CAD–CAM concepts are, respectively, −40, −76, −135, and −177 μm. These numbers represent the “systematic errors” of the respective CAD–CAM concepts. We hope that our dentist or dental technician team has purchased CAD–CAM concept “A.” Trueness is excellent, and even though the precision is not excellent, it is still good. In this hypothetical graph, one may see that all the crowns have a fit better than −100 μm. CAD–CAM concept “B” could perhaps also be tolerated because its trueness is less than −100 μm and therefore good, but the precision is average, signifying that any received crown can have a fit ranging from excellent to poor. In this hypothetical illustration it ranges from 0 to −160 μm. CAD–CAM concept “C” has excellent precision, but we should not be impressed because its trueness is far from 0; in this graph, the average fit of 125 μm and ranging from 90 to 160 μm. CAD–CAM concept “D” is hopefully not the one our dentist purchased because they perhaps liked the payment plan and shiny looks of the CAD–CAM machine, but forgot to ask about its precision and trueness.

Corresponding reasoning applies to any digital technology intended for diagnostic purposes or for CAD–CAM of dental devices. To reinforce the key message, “accuracy” is a combination of “trueness” and the “precision.” Any dental professional who considers purchasing a digital device can create a figure as illustrated, even though this may perhaps be a bit impractical. Luckily, “accuracy” can also be described statistically in different ways. The preferable statistics is known as Root Mean Square Error (RMS), but alternatives can be the x standard deviation (also known as Sigma) or, for example, 50%, 67%, 75%, or 95%-percentile values relative to what you as a professional consider is clinically or technologically relevant accuracy.

The statistically savvy will rightly point out that a deliberation about accuracy should include a discourse on “confidence interval”. However, statisticians use the term “accuracy” differently from engineers and knowledgeable clinicians, who have adopted the ISO definition that accuracy combines trueness and precision.

The good news is that you really do not need to understand the multitude of confusing verbiage frequently adopted in red herring sales strategies. Therefore, do not feel bad if you suddenly feel overwhelmed during a purchase negotiation of a digital appliance by the barrage of unfamiliar terms including, but not limited to “application error,” “registration error,” “positioning error,” “localization error,” “targets,” or “fiducial markers.” Discussing the numbers for accuracy, precision, and trueness should suffice.

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FIGURE 1 Measurement of marginal fit of dental devices made from four hypothetical CAD–CAM concepts (“A”, “B”, “C”, “D”) shown by distribution curves. The closeness of the curves to the left axis implies trueness, i.e., how close they are to the intended value = 0 μm. The form of the curves implies precision, i.e., a narrow (and tall) curve indicates good precision and a wide (and short) curve the contrary. (The area under the respective curves equals to 100% of the measurements, which accounts for the variation in total height of the curves). The green background shade implies clinical acceptable, red the contrary. The terms “excellent”, “good”, “average”, “poor” are qualitative only.

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