Cureus
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Open Access Review Article

Dimensional Measurement in Dentistry: Conventional Calipers, Digital Workflows, and Emerging Devices for Soft Tissue Graft Assessment

Review began 10/23/2026
Review ended 11/04/2026
Published 11/10/2026

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DOI: 10.7759/cureus.119414

Raed AlRowis [1]

1. Department of Periodontics and Community Dentistry, College of Dentistry, King Saud University, Riyadh, SAU

Corresponding author: Raed AlRowis, ralrowis@ksu.edu.sa

Abstract

This review examines methods for measuring linear dimensions in dentistry using calipers and digital workflows, with a recently patented two-probe soft-tissue caliper serving as a case study for soft-tissue graft dimensioning. PubMed/MEDLINE, Scopus, and Web of Science were searched for literature published between January 1990 and September 2026. Patent databases and relevant metrological standards were also consulted; seminal earlier sources were added where they defined methods used in the review. Systematic reviews and agreement studies with explicit reference standards were prioritised. For tooth and arch dimensions, digital models showed agreement with caliper measurements on casts, with mean bias close to zero and 95% limits of agreement within approximately ±0.5 mm; agreement between two methods does not establish the trueness of either. Soft-tissue thickness measurements varied by method, with reported mean palatal mucosal thickness ranging from approximately 2.4 mm using ultrasound to 4.4-5.8 mm using sharp-cannula sounding, a range that may also reflect differences in anatomical site, population, and protocol. None of the methods evaluated in the reviewed studies measured the thickness of the planned palatal graft before harvesting. The patented caliper combines adjustable span setting with colour-coded depth indication in a single instrument intended for intraoperative graft planning, but no performance data have been published. Clinicians should select measurement methods validated for the specific quantity being assessed. New graft-dimensioning devices require staged bench, ex vivo, and clinical evaluation before claims of standardisation or improved clinical outcomes can be supported.

Categories: Dentistry
Keywords: caliper, dental materials science, materials science, regenerative periodontist, soft tissue surgery

Introduction And Background

Many clinical decisions in dentistry depend on linear measurements expressed in millimetres. Mesiodistal tooth widths determine tooth-size discrepancy in Bolton analysis [1]; the thickness of a coping or veneer determines whether a restorative material can be used; gingival thickness is part of the periodontal phenotype [2]; flap thickness is associated with the outcome of root-coverage surgery [3]; and the thickness of a palatal graft influences its composition and the morbidity of harvesting [4,5]. These quantities are obtained with very different instruments: sliding and spring calipers, periodontal probes and endodontic files, optical scanners, cone-beam computed tomography (CBCT), and ultrasound.

The literature often compares these instruments as if they measured the same anatomical parameter. For rigid objects such as teeth and casts, this assumption is broadly justified, and the comparison of digital and plaster models has been examined in several systematic reviews [6,7]. For soft tissues, it does not hold. Gingival thickness values obtained with probes, needles, ultrasound, and CBCT differ systematically [8,9], and palatal thickness values reported in the literature vary by more than 2 mm according to the method used, although differences in anatomical site, study population, endpoint definition, and measurement protocol may also contribute. At the point of greatest surgical consequence (deciding how deep to incise when harvesting a palatal graft), clinicians still rely largely on a periodontal probe and visual judgement [10,11].

Precise graft dimensioning is clinically important. Autogenous connective tissue grafts are the current reference standard for soft-tissue augmentation [5], but the postoperative morbidity associated with their harvest is considered the main limitation of the procedure. The dimensions and the technique of harvesting affect morbidity [4,12]. The recommended optimal palatal graft thickness is 1-1.5 mm [10].

However, the reported thickness of the palatal mucosa varies between 2.4 and 5.8 mm, depending on the site and the method of measurement [13,14]. Other reviews have examined digital models [6,7] and various methods for determining gingival thickness [9] separately. To the best of our knowledge, no review has examined whether the instruments assessed in these three domains measure the same quantity.

This review therefore has four aims: (i) to set out the metrological concepts needed to compare dental measurement methods; (ii) to appraise the evidence for conventional, electronic, and digital methods applied to teeth and casts; (iii) to appraise methods for measuring soft-tissue thickness, with emphasis on the palatal donor site; and (iv) to use a recently granted patent for a two-probe soft-tissue caliper [11] as a case study, examining its claims, prior art, and the evidence that would be needed before clinical adoption. The review is narrative and does not replace a systematic review of any single question.

Review

Methods

The review was planned and reported with reference to the Scale for the Assessment of Narrative Review Articles (SANRA) [15]. PubMed/MEDLINE, Scopus, and Web of Science were searched from January 1990 to September 2026 using combinations of the following terms: (caliper OR calliper OR "Boley gauge" OR Iwanson) AND (dental OR tooth OR cast); ("digital model*" OR "intraoral scan*") AND (accuracy OR agreement OR validity) AND (orthodont* OR "tooth width" OR impression); ("gingival thickness" OR "palatal mucosa" OR "masticatory mucosa") AND (transgingival OR ultrason* OR "cone-beam" OR histolog*); and ("connective tissue graft" OR "free gingival graft") AND (harvest* OR thickness OR morbidity). Google Patents and Espacenet were searched using Cooperative Patent Classification codes A61B90/06, G01B3/28, and G01B5/18 and the terms "tissue caliper" and "graft thickness", and all documents cited by the examiner against US12,140,420 B1 were reviewed. Reference lists of included articles were hand-searched, and seminal sources published before 1990 were added because they define methods used in this review. Systematic reviews and meta-analyses were given priority, followed by agreement and diagnostic-accuracy studies that used an explicit reference standard (histology, direct measurement after flap elevation or extraction, a coordinate-measuring machine, or a calibrated caliper). Studies reporting only correlation coefficients without agreement statistics were used descriptively. Manufacturer documents and patents were used to describe design and intended use, never as evidence of performance. Consistent with the narrative design, sources were selected for their relevance to the four aims rather than to achieve exhaustive coverage. In total, 56 sources were cited: 41 peer-reviewed journal articles, seven metrological standards and official guidelines (Joint Committee for Guides in Metrology (JCGM), International Organization for Standardization (ISO), and Centers for Disease Control and Prevention (CDC)), two manufacturer documents, and six patent documents.

A Metrological Framework for Dental Measurement

Defining the measurand: The International Vocabulary of Metrology (VIM) defines the measurand as the quantity intended to be measured [16]. Defining it requires the object, the two endpoints, and the direction. "Gingival thickness" measured 2 mm apical to the free gingival margin is a different measurand from thickness at the mucogingival junction; "palatal mucosal thickness" sounded to the periosteum with a blunt probe is a different measurand from thickness sounded to bone with a sharp cannula. When two studies define the measurand differently, their disagreement is not evidence that one instrument is inaccurate. Figure *1* illustrates four measurands that are often conflated: tooth width on a rigid cast, keratinised tissue width (a surface distance), gingival thickness (a transmural distance), and the three distinct quantities at a palatal donor site.

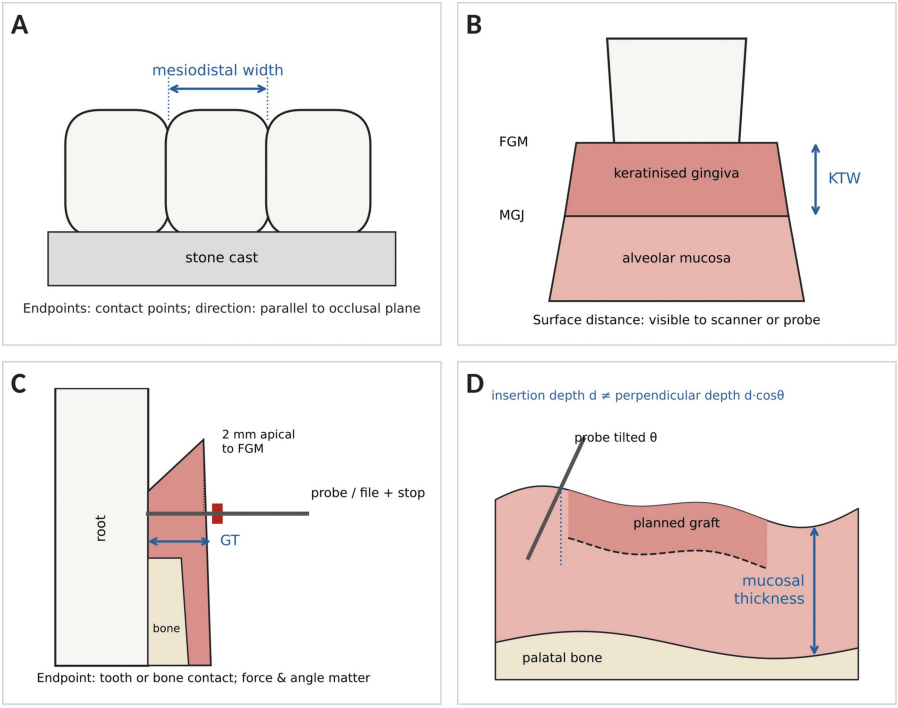


FIGURE 1: Four measurands commonly conflated under the term "dimension".

(A) Mesiodistal tooth width on a rigid cast, defined by contact points and a direction. (B) Keratinised tissue width (KTW), a surface distance between the free gingival margin (FGM) and the mucogingival junction (MGJ), accessible to optical scanning. (C) Gingival thickness (GT) measured transgingivally, conventionally 2 mm apical to the FGM, whose value depends on the endpoint, insertion angle, and force. (D) At a palatal donor site, preoperative mucosal thickness, the planned graft thickness, and the indicated insertion depth of a probe are three different quantities; a probe tilted by θ from the surface normal reaches a perpendicular depth of d·cos θ. Original illustration created by the authors using Python (version 3.13; Python Software Foundation, Wilmington, Delaware) and the Matplotlib plotting library (version 3.11).

Trueness, precision, resolution, and uncertainty: Trueness describes the closeness of the mean of repeated measurements to a reference value; precision describes the closeness of repeated measurements to one another under stated conditions and is subdivided into repeatability (same operator, instrument, and conditions) and reproducibility (changed conditions, such as a different examiner) [16]. Reliability is typically reported as an intraclass correlation coefficient (ICC) and describes how well a method differentiates between subjects relative to measurement error, whereas agreement describes how well two methods agree. Reliability and agreement are necessary conditions for trueness but are not sufficient, in that the comparator must be a valid reference. Resolution is the smallest change in the quantity that will produce a perceptible change in the indication. These properties are independent; an electronic caliper has fine resolution (0.01 mm), and the maximum permissible error is separately specified in ISO 13385-1 [17]. The uncertainty due to the selection of landmarks, instrument tilt, and contact force is usually significantly greater than these values. In dental studies, this contribution is rarely reported, but the Guide to the Expression of Uncertainty in Measurement (GUM) presents an approach for combining all these contributions into an uncertainty budget [18].

Agreement is not correlation: Two methods can have a correlation that is almost perfect but differ by a constant or proportional amount. If the question is whether one method can be substituted for another, then the appropriate analysis is the mean difference (bias) with 95% limits of agreement [19], compared with a clinically acceptable difference specified in advance. Intraclass correlation coefficients (ICCs) are used to measure reliability; the form of the ICC, its type, and its definition should be reported because different forms of ICC from the same data give different values [20]. Reliability and agreement studies should follow the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) [21], and studies that classify patients (for example, thin versus thick gingiva) should follow the Standards for Reporting Diagnostic Accuracy Studies (STARD) [22].

Reference standards: No agreement study is more informative than its reference standard. For dental casts and dental digitisers, the reference is provided by a calibrated caliper or coordinate-measuring machine, and ISO 12836 establishes test methods to determine the accuracy of dental digitising devices [23]; Ender and

Mehl introduced a reference-scanner method that separates trueness from precision for complete-arch impressions [24]. For soft tissue, histology is the reference standard ex vivo, while direct caliper measurement after flap elevation or extraction and transgingival probing (TGP) serve as clinical references [25,26]. Each carries its own bias: histological processing shrinks tissue, a cadaver or porcine model lacks perfusion and tone, and TGP compresses tissue along its path.

Conventional and Electronic Calipers

Instrument types: Dental calipers form a family of instruments with different contact geometries rather than a single device (Table *1*). The Boley gauge (HuFriedyGroup, Chicago, Illinois) is a vernier sliding gauge used for length, width, and thickness on teeth and casts [27]. Pointed or needle-tipped sliding calipers, usually with an electronic readout, are used for mesiodistal widths on casts because their tips reach interproximal contacts. Iwanson-type spring calipers (e.g., CLP1; HuFriedyGroup, Chicago, Illinois), with opposing pointed jaws and a dial, measure the thickness of metal, porcelain, and wax [28]. Tension-free spring calipers are also used on soft tissue that has been reflected or removed (for example, to measure gingival thickness after extraction [25]), which makes them a natural instrument for checking the thickness of a harvested graft.

Instrument/method	Measurand	Typical use	Readout	Dominant error sources	Evidence of validity
Boley (vernier) gauge	Linear distance between jaws	Teeth, casts	Vernier scale	Scale reading, jaw access, tilt	Manufacturer documentation [27]; widely used reference
Pointed electronic caliper	Mesiodistal width between contact points	Casts (Bolton, space analysis)	0.01 mm display	Contact-point identification, tilt, cast fidelity	Reference in digital-model studies [7,29]
Iwanson spring caliper	Material thickness between opposing points	Copings, porcelain, wax	Dial	Contact force on soft materials	Intended use per manufacturer [28]
Tension-free caliper on specimen	Thickness of reflected or removed tissue	Extracted-site gingiva; harvested graft	Dial/display	Tissue compression, drying, specimen curvature	Used as reference [25]
Periodontal probe, file or needle (TGP)	Insertion depth to a mechanical endpoint	Gingival or palatal thickness	1 mm probe marks, or stop read with caliper	Angle, endpoint (periosteum vs bone), tip, force, anaesthesia	Clinical reference for GT [8,26]
Optical scan + software	Surface distance (and volume change)	Casts, dentition, KTW	Software	Landmarking, stitching, acquisition route	Valid agreement with caliper for tooth/arch dimensions [7,30]; KTW [31]
CBCT (± scan superimposition)	Radiographic distance between interfaces	Gingival thickness, bone	Voxel-dependent	Voxel size, lip/cheek contact, registration	Comparable to TGP in several studies [25,32,33]
Ultrasound	Acoustic distance to an echo interface	Gingival and palatal thickness	Device-dependent (e.g. 0.1 mm)	Probe angulation, site relocation, rugae	Good agreement with histology preclinically [34]; regional variation [9]
Two-probe soft tissue caliper (US 12,140,420 B1)	Span between probes; insertion depth at two points	Palatal graft planning (proposed)	Ruler; colour bands at 1 mm	Band interpolation, probe tilt, deformation, endpoint	None published [11]

TABLE 1: Measuring instruments and methods grouped by the measurand they address.

CBCT, cone-beam computed tomography; GT, gingival thickness; KTW, keratinized tissue width; TGP, transgingival probing.

Measuring teeth and casts: The most common method used for checking the accuracy of digital models is to make a caliper measurement on a plaster cast [7], and errors accumulate when the mesiodistal widths of six or 12 teeth per arch are summed [1]. The principal sources of error are identification of contact points in crowded segments, tilt of the caliper relative to the occlusal plane, and the dimensional fidelity of the impression and cast. A caliper cannot correct an inaccurate cast.

Electronic readout: Electronic calipers retain the contact geometry of mechanical calipers and change only the readout, which removes errors in reading the vernier (the small sliding scale used to read fractions of a millimetre) and allows direct data capture. Liu and colleagues measured 2,800 teeth on 100 pairs of plaster models with an electronic caliper and on structured-light scans of the same models; ICCs exceeded 0.75 for intra- and interobserver reliability, mean bias was close to zero, and the 95% limits of agreement were within ±0.5 mm [29]. Because both methods measured the same cast, this establishes agreement between the two methods, not the trueness of either relative to the patient's dentition; the ICCs describe reliability, not trueness.

Restorative and laboratory thickness checks: Spring calipers are used to confirm the minimum material thickness of copings, frameworks, and wax patterns. Minimum thicknesses are material- and system-specific and must be taken from the manufacturer's instructions; no single value applies across materials. The contact force that is appropriate for metal will deform wax or soft tissue, so the measuring technique must match the stiffness of the specimen.

Digital Models, Intraoral Scanning, and Automated Measurement

Evidence for linear measurements: The agreement of digital models with caliper measurements for orthodontic linear measurements is well established. An early systematic review concluded that differences between digital and plaster models were generally small and clinically acceptable [6]. Rossini and colleagues reviewed 35 studies published between 2000 and 2014 and found no significant differences for most parameters other than the American Board of Orthodontics Objective Grading System; they identified landmark identification, rather than the device or software, as the main limitation [7]. For direct intraoral scanning in patients, Kong and colleagues included 22 in vivo studies (13 in a meta-analysis) and found no significant differences from conventional impressions for tooth width, Bolton ratios, intercanine and intermolar distances, with a three-dimensional deviation from alginate of 0.09 mm; their conclusion was restricted to fully dentate arches [30]. The range of scanners and orthodontic applications is summarised by Jedliński et al. [35].

Workflow, not technology, determines accuracy: Agreement between a scan and a caliper on the same cast establishes agreement between methods, not the trueness of either method relative to the dentition. While there is no casting error with intraoral scanning, there are stitching errors that accumulate across an entire arch. Therefore, claims concerning the accuracy of "digital" measurement are only meaningful if the acquisition path, the scanner, the software, and the measurand are reported [24,35].

Automated measurement: Model analysis can be largely automated with segmentation and landmark detection. Nguyen et al. reported an ICC of 0.967 and a mean absolute error of less than 1 mm for tooth width automatically measured on CBCT and plaster models, compared with manual caliper measurements by orthodontists [36]. The mean absolute error is acceptable for screening, but an error approaching 1 mm per tooth is large compared with the cumulative sums employed in Bolton analysis, and therefore automated output still needs to be verified. CBCT should not be acquired solely to obtain such measurements [37].

In summary, for teeth and casts, the question of whether digital measurement can replace caliper measurement has largely been answered for dentate patients. The remaining questions concern edentulous and implant cases and the soft tissues, to which this review now turns.

Soft-Tissue Thickness: A Method-Dependent Measurand

Phenotype, width, and thickness: The 2017 World Workshop described the periodontal phenotype in terms of gingival phenotype (gingival thickness and keratinised tissue width) and bone morphotype [2]. Phenotype is frequently classified by probe transparency through the sulcus, which is a dichotomous test rather than a measurement [38]. Keratinised tissue width is a surface distance: in five porcine jaws (110 sites) with histology as the reference, measurements on intraoral scans were more accurate than probe measurements and more reliable (ICC 0.97 versus 0.87) [31]. That finding concerns width, which a scanner can see; it cannot be extrapolated to thickness, which lies beneath the surface.

Gingival thickness: Four principal approaches are used to measure gingival thickness: TGP with a probe, endodontic file, or needle; ultrasound; CBCT, alone or superimposed on an intraoral scan; and direct measurement after flap elevation or extraction (Table *2*). In 200 orthodontic patients, TGP with a standard periodontal probe was more accurate than an acupuncture needle after method-error assessment, and both the needle and ultrasound produced higher values than the probe [8]. In porcine mandibles, probe and needle gave almost identical means (1.11-1.14 mm), whereas ultrasound and CBCT gave systematically higher values [39]. In 40 patients, CBCT values were 0.13-0.21 mm higher than ultrasound [33]. When intraoral scanning of sectioned porcine specimens was taken as the true value, TGP with a metal probe showed mean differences between −0.17 and 0.04 mm, supporting its use as the clinical reference [26]. In patients undergoing extraction, values obtained by superimposing CBCT or intraoral-scan files were similar to those obtained by horizontal TGP with an endodontic spreader [25], and in a cadaver in which horizontal TGP was performed with an endodontic spreader, CBCT was found to reliably represent labial gingival thickness [32].

When compared with histology, ultrasound showed good-to-excellent agreement for soft-tissue thickness (ICC 0.77-0.96) [34].

Study	Method (endpoint)	Sample	Principal finding	Implication
Müller et al. 1999 [13]	Ultrasound (acoustic interface)	11 subjects; buccal, lingual, palatal sites	Palatal mean 2.36 ± 0.87 mm, measurement error 0.54 mm (buccal 0.26 mm)	Palatal ultrasound less reliable; rugae and relocation
Studer et al. 1997 [40]	Bone sounding, probe	31 subjects; 18 palatal points	Thickness maps of palate and tuberosity	Point-based mapping of donor tissue
Wara-aswapati et al. 2001 [41]	Bone sounding, probe	62 subjects, 14–59 years	Overall mean ≈3.0 mm; thinner over first molar	Site-specific variation
Song et al. 2008 [42]	Computed tomography	100 subjects; 24 points	Mean 3.83 ± 0.58 mm	Radiographic values exceed ultrasound
Schacher et al. 2010 [14]	Sharp cannula with stop, under local anesthesia	33 participants	4.39 ± 1.05 mm (first molar) to 5.75 ± 1.78 mm (second molar)	Higher than blunt probe or ultrasound
Kloukos et al. 2018 [8]	Probe TGP, needle TGP, ultrasound, color probe	200 orthodontic patients	Probe most accurate; needle and ultrasound higher	Gingival methods not interchangeable
Gkogkos et al. 2020 [39]	Probe, needle, ultrasound, CBCT	20 porcine mandibles	Probe ≈ needle (1.11–1.14 mm); ultrasound and CBCT higher	Systematic offset of imaging methods
Kloukos et al. 2021 [33]	Ultrasound vs CBCT	40 adult patients	CBCT 0.13–0.21 mm higher than ultrasound	Small offsets matter near 1 mm threshold
Kloukos et al. 2021 [26]	Probe TGP vs scan of sectioned specimen	20 porcine cadavers	Mean differences −0.17 to 0.04 mm	TGP acceptable clinical reference
Couso-Queiruga et al. 2021 [25]	CBCT–scan superimposition vs spreader TGP or spring caliper	Patients before extraction	Digital values comparable to spreader TGP	Non-invasive alternative for buccal gingiva

TABLE 2: The method dependence of gingival and palatal soft-tissue thickness from selected studies.

Values are reported as in the original publications. CBCT, cone-beam computed tomography; TGP, transgingival probing.

The differences between methods in these studies are generally 0.1-0.3 mm. This is a large fraction of the thickness of approximately 1 mm, the threshold commonly used to separate thin from thick gingiva [2], so systematic differences between methods would directly correspond to phenotype misclassification. A systematic review of 12 studies showed that agreement between ultrasound and TGP varied by region; there was a significant difference in the posterior region [9]. Similarly, Soltani et al. performed a systematic review of 12 studies that used a K-file with a rubber stop, read using a digital caliper, and found differences in agreement between anterior and posterior regions [37]. In that protocol, the caliper only adds the final reading to the uncertainty, while the dominant uncertainty comes from the insertion, angle, and endpoint detection.

Palatal donor-site thickness: In the case of grafting, the tissue harvested is palatal masticatory mucosa, and the method dependence is much more pronounced (Table *2*). Müller et al. [13] measured palatal thickness in 11 subjects using ultrasound and reported a mean thickness of 2.36 ± 0.87 mm, with a 0.54 mm error, which was twice the 0.26 mm error at the buccal gingiva, and attributed the difference in reliability to the rugae and the difficulty of repositioning the sites. In 62 subjects aged 14 to 59 years, bone sounding with a periodontal probe gave an overall mean thickness of approximately 3.0 mm, which increased from canine to molar (except across the first molar) [41]. Computed tomography in 100 subjects gave 3.83 ± 0.58 mm [42]. The 4.39 ± 1.05 mm measured in the first-molar region and 5.75 ± 1.78 mm measured in the second-molar region by direct sounding with sharp, single-use cannulas under local anaesthesia were significantly greater than the values found with blunt probes or ultrasound, as the authors expressly noted [14].

The range of values (2.4-5.8 mm) is unlikely to be explained solely by differences in anatomical site or population. It largely reflects different measurands: a blunt probe may stop at dense periosteum while a sharp cannula reaches bone; ultrasound detects an acoustic interface rather than a mechanical endpoint;

and infiltration of local anaesthetic may alter tissue dimensions. For clinical purposes, the practical consequences are that values from different methods must not be pooled and that a thickness obtained by one method cannot be used as a threshold for another. Individuals with thin gingiva also tend to have thin palatal mucosa [43], so the patients most in need of a graft may be those with the least donor tissue.

From donor-site thickness to graft thickness: Three different quantities must be distinguished at a donor site (Figure *1D*): the preoperative mucosal thickness, the planned incision depth during surgery, and the thickness of the graft actually obtained. Probe angulation adds a further error: a probe inserted to an indicated depth d at an angle θ to the surface normal reaches a perpendicular depth of only d·cos θ, about 0.1-0.3 mm less than indicated for insertions of 1.5-2 mm at 20-30° (Figure *2*). A connective tissue graft of about 1-1.5 mm is commonly sought [10,11]. Its composition, dense lamina propria versus submucosa containing adipose and glandular tissue, depends on the harvesting technique and the depth of dissection [5,10]; the technique also influences donor-site morbidity [4]. The single-incision technique [44] gives the clinician little direct view of the dissection plane, and the location of the greater palatine neurovascular bundle varies with the height of the palatal vault [45]. Flap thickness has been associated with the likelihood of complete root coverage [3], so graft and flap dimensions are not merely technical details.

None of the methods reviewed above measures the thickness of a graft before it is cut. Preoperative mapping (ultrasound, sounding, or CBCT) describes the donor tissue; a probe can mark an intended depth at isolated points; and a tension-free caliper can measure the harvested graft after removal, when the only remaining corrective option is to trim it. This is the gap that intraoperative graft-dimensioning devices attempt to address.

Infection prevention and device suitability: Any instrument that penetrates soft tissue is a critical item and, if reusable, must be cleaned and heat-sterilised; heat-tolerant semicritical items should also be heat-sterilised [46,47]. The majority of electronic calipers are not heat-sterilisable and thus can only be used for casts or laboratory work or on a sterile field with specimens harvested in a sterile sheath. Hinges, sliding tracks, and locking mechanisms make cleaning difficult and must be taken into consideration in the validated reprocessing instructions, while patient-contacting materials need to be evaluated biologically [48]. Therefore, it is not surprising that reprocessing is considered an integral part of the assessment of a new measuring device rather than a standalone issue.

Case Study: A Two-Probe Soft-Tissue Caliper (US 12,140,420 B1)

Description: US 12,140,420 B1, entitled "Soft Tissue Caliper", was filed on May 6, 2024, and granted on November 12, 2024, to R.M. Alrowis and Z.S. Natto, with King Saud University as the assignee [11]. It has seven claims. Claim 1 is directed to a fixed probe, with the movable probe similarly configured to be insertable into tissue and to include a depth indicator, mounted on a ruler resting on a fixed base and a movable base with a movable part that slidably adjusts the distance between the probes. Claims 2-4 specify colour depth indicators, with grey bands at 1, 4, and 7 mm, blue at 2, 5, and 8 mm, and red at 3, 6, and 9 mm; claims 5 and 7 add a button that locks the movable base. The specification describes needle-like probes of about 9 mm and a method in which the fixed probe is placed at the graft site, the movable probe is slid to the desired graft length and locked, and both probes are pushed in to the desired depth (for example, to the first blue band for 2 mm), after which the practitioner removes the graft (Figure *2*) [11]. The device has no cutting element; its claims concern measurement and marking only.

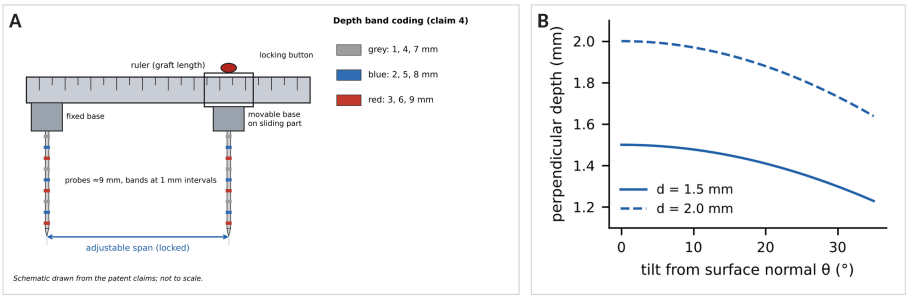


FIGURE 2: Two-probe soft tissue caliper as shown in US 12,140,420 B1 (not to scale).

The span of the graft is set along a ruler by a fixed probe and a movable probe on a lockable sliding base, with colour bands every 1 mm in a repeating grey–blue–red sequence on each probe (≈9 mm). The perpendicular depth of insertion for 1.5 mm and 2.0 mm insertions as a function of the angle of probe tilt from the surface normal ($d \cdot \cos\theta$) is shown in the inset. Original illustration created by the author using Python (version 3.13; Python Software Foundation, Wilmington, Delaware) and the Matplotlib plotting library (version 3.11), based on the description and claims of US 12,140,420 B1; it does not reproduce the patent drawings [11].

The specification states the problem as variability of graft thickness, the difficulty of obtaining a uniform graft of about 1 mm from an uneven palate, the 15 mm limit of a periodontal probe for graft length, and the inability of mucotomes to measure tissue thickness. It describes the intended benefits as uniform, standardised graft thickness that is reproducible between practitioners. No bench, ex vivo, or clinical data are reported [11], and no independent evaluation of the device had been published at the time of writing; these intended benefits are therefore untested.

Prior art and novelty: The examiner cited prior documents that include a surgical caliper [49], a skin-fold caliper [50], a device for measuring length and depth [51], a tissue caliper [52], and a sliding caliper for tissue thickness [53]. Clinically, the separate functions already exist: a periodontal probe or a file with a stop indicates insertion depth [37], bleeding points made with a probe mark graft outlines, and a sliding caliper sets a span. The contribution of the patented device lies in combining two depth-graduated penetrating probes on a lockable sliding beam for oral graft planning. This combination allows graft length and depth to be set with one instrument, but its effect on graft dimensions remains to be determined through the evaluation pathway described below.

A validation pathway: The IDEAL (Idea, Development, Exploration, Assessment, and Long-term study) framework for surgical innovation and its device-specific extension IDEAL-D propose staged evaluation from preclinical work to comparative trials and long-term monitoring [54,55]. Table *3* sets out a pathway for a graft-dimensioning device. Bench testing in layered elastomer phantoms of known thickness should quantify bias, repeatability, and the error of interpolating between bands by several examiners, with results reported as limits of agreement and correctly specified ICCs [19-21]. Ex vivo testing in porcine palates should compare indicated depth with histological depth at the puncture sites and, more importantly, compare device-guided with conventional probe-guided harvesting by novice and experienced operators, with the thickness of each harvested graft measured at a predefined grid of points (for example, nine) with a calibrated tension-free caliper. The primary outcomes should be the mean absolute deviation from the planned thickness and the within-graft standard deviation, which captures uniformity.

Stage	Setting and comparator	Primary outcomes	Design and reporting notes
Bench (pre-IDEAL)	Layered elastomer phantoms of known thickness; several examiners	Bias and 95% limits of agreement for indicated depth; band-interpolation error; repeatability	Prespecify acceptable difference (e.g. ±0.25 mm); ICC form stated [20]; GRRAS [21]
Ex vivo (Idea/Development) [54,55]	Porcine palates; histology at puncture sites; device-guided vs probe-guided harvest by novice and expert operators	Mean absolute deviation of harvested graft from planned thickness; within-graft SD at a 9-point grid	Calibrated tension-free caliper or histology as reference; operator as random effect
Early clinical (Exploration) [54,55]	Prospective series, defined indication (e.g. CTG for root coverage)	Feasibility, handling, readability in bleeding field, adverse events	Report learning curve; control anaesthetic volume
Comparative (Assessment)	RCT: device-guided vs conventional harvesting	Deviation from target thickness and uniformity; secondary: time, bleeding, pain, analgesic use, healing, root coverage at 6–12 months	≈36 grafts per group for 0.2 mm difference (SD 0.3 mm, α 0.05, power 0.8); STARD for accuracy components [22]; independent investigators
Long-term (Long-term study)	Registry or post-market follow-up	Complications, reprocessing performance, device failures	Biological evaluation and validated reprocessing [47,48]

TABLE 3: Proposed staged evaluation of an intraoperative graft-dimensioning device, aligned with IDEAL-D.

CTG, connective tissue graft; ICC, intraclass correlation coefficient; RCT, randomised controlled trial; SD, standard deviation; IDEAL-D, Idea, Development, Exploration, Assessment, and Long-term study framework for devices; GRRAS, Guidelines for Reporting Reliability and Agreement Studies.

A clinical randomised trial would then compare device-guided and conventional harvesting. To detect a difference of 0.2 mm in the mean absolute deviation from the target, with a standard deviation (SD) of 0.3 mm, $\alpha = 0.05$ on a two-tailed test, and 80% power, approximately 36 grafts per group are needed. Secondary outcomes should consider time to harvest, intraoperative bleeding, donor-site pain scores, amount of analgesics used, healing, and recipient-site outcomes (root coverage at 6-12 months). The accuracy components should be reported as per STARD [22]. It would be strong evidence if there were at least one comparative evaluation by independent investigators, given that the inventors and assignee have a legitimate interest in the device.

Discussion

The reviewed evidence does not suggest a general order of superiority of digital methods over mechanical ones. In dentate arches, digital models/virtually scanned models can be compared with caliper measurements, with acceptable differences in tooth and arch dimensions for orthodontic analysis [7,29,30], and the choice can be based on convenience, storage, and cost. The values are method-dependent for soft tissue: probes, needles, cannulas, ultrasound, and CBCT stop at different interfaces and deform tissue to varying degrees, resulting in different values [8,14,39]. In this case, the most significant methodological step is to define and report the "measurand site", "reference line", "endpoint", instrument tip, "force", and "anaesthetic state", not to obtain higher resolution of the display. These results add to previous systematic reviews that validated digital models for orthodontic measurement [6,7] and compared methods for measuring gingival thickness [9]. These reviews, however, treated each application separately. The apparent discrepancies among soft-tissue measurement methods discussed in this review may reflect differences in what each method measures. Recent histological data support this: ultrasound and CBCT underestimated gingival thickness, while transgingival probing overestimated it, all with a high degree of clinical accuracy, in 16 human cadaver heads [56]. These findings contrast with the above-mentioned directions of bias, where ultrasound and CBCT resulted in higher values than probing [8,33,39]. The difference is due to the comparator and the model used: in [56], each method was compared with histology in human cadavers, and the tissue shrinks during histological processing; the earlier studies used probing as a comparator in patients or in porcine tissues. It is important to recognise that the direction of a method's bias is dependent upon the reference standard and should not be extrapolated between studies. A thin/thick histological gingival thickness cut-off of 1.18 mm was found to be more accurate than the conventional 1 mm cut-off. It has also been shown that graft dimensions and harvesting technique influence graft composition and donor-site morbidity [4,10,12]. It is also clinically relevant that no methodology in the reviewed literature verified graft thickness prior to the release of the graft. Some of the instruments being designed to measure soft-tissue grafts incorporate a caliper-type device to set the span and depth of the graft. Whether such instruments address this gap remains a hypothesis to be tested.

There are four research needs: First, a consensus protocol for palatal thickness mapping (site grid, instrument, endpoint, and anaesthesia) would enable pooling of the results. Second, intraoperative assessment of graft thickness, prior to release of the graft, remains unresolved; ultrasound, which has been shown to have good agreement with histology preclinically [34], and sterile tension-free calipers for immediate verification after harvest are candidates. Third, bias and limits of agreement should be reported in agreement studies in relation to prespecified clinical thresholds and according to GRRAS and STARD [21,22]. Fourth, devices are under development to improve graft dimensioning, among them the one studied here, and must be evaluated in several stages before claims of standardisation or improved outcomes can be made [55].

There are limitations to this review. It is narrative, and the search was structured, but study selection may be biased. A great deal of the soft-tissue evidence is from porcine or cadaver models, which have no perfusion or tissue tone. Only the published claims and specification of the patented device were used for appraisal, and no physical device was examined.

Conclusions

Within the scope of this narrative review, measurement methods should be chosen and compared based on what they measure rather than on display resolution. Digital models and intraoral scans are acceptable alternatives to caliper measurements on casts for assessing tooth and arch dimensions in dentate patients. Values of gingival and palatal thickness, on the other hand, depend on the method used to measure them and should not be pooled or used interchangeably as thresholds. No technique in the reviewed literature measured the thickness of palatal grafts prior to their removal, and whether insertion depth at two points predicts their thickness or uniformity remains to be tested. The patented two-probe soft-tissue caliper combines adjustable span setting and depth indication in one instrument intended to support surgical planning of graft length and depth; its proposed benefits remain to be demonstrated through independent bench, ex vivo, and clinical studies.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Raed AlRowis

Acquisition, analysis, or interpretation of data: Raed AlRowis

Drafting of the manuscript: Raed AlRowis

Critical review of the manuscript for important intellectual content: Raed AlRowis

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Intellectual property info:** R. Alrowis is one of the named inventors on U.S. patent 12,140,420 B1 (Soft tissue caliper), which is assigned to his institution, King Saud University, and is discussed in this review. No other relationships or activities that could appear to have influenced the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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