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White Paper – Limb Length

BIOMECHANIGG
SPORT & HEALTH RESEARCH

A white paper for Innovations Health
Devices to quantify lower-limb segment
lengths for the development of the Kinoped.

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Introduction

Limb length is a fundamental anthropometric measurement representing the structural length of a limb segment, typically calculated as the sum of its constituent skeletal components (Varela-Silva & Bogin, 2012). Lower-limb length is widely used across clinical practice, sports science, biomechanics, and rehabilitative engineering, where accurate measurements inform diagnosis, performance evaluation, and the design of assistive technologies. In clinical settings, leg length is routinely assessed during childhood, when rapid skeletal growth allows clinicians to identify lower-limb length discrepancies and abnormalities in musculoskeletal development (Varela-Silva & Bogin, 2012). Within sports science, lower-limb length has been associated with mobility, stride characteristics, and movement efficiency, highlighting the influence of anthropometric proportions on athletic performance (Kwon & Kim, 2025). Similarly, in rehabilitation and assistive technology, lower-limb dimensions are essential for tailoring wearable robotic systems to an individual's anatomy, ensuring appropriate fit and function (Laubscher et al., 2021).

Accurate quantification of limb length is particularly critical in the development and application of wearable robotic exoskeletons, where biomechanical alignment between the device and the user directly influences performance, comfort, and safety. These systems interface closely with the human musculoskeletal system and rely on precise anthropometric measurements to achieve proper joint alignment and accurately evaluate motor performance through embedded sensing technologies (Moeller et al., 2023). Inaccurate limb length measurements can result in joint misalignment between the exoskeleton and the user, leading to undesirable interaction forces, impaired movement quality, reduced device effectiveness, and an increased risk of discomfort or injury (Zanotto et al., 2015; Moeller et al., 2023). Consequently, reliable anthropometric data are fundamental to the design, calibration, and clinical implementation of robotic exoskeletons and other lower-limb assistive devices.

Although normative lower-limb length measurements for healthy adults have been reported throughout the scientific literature, these data remain fragmented across studies conducted within diverse disciplines and for differing research objectives. Existing measurements are often reported in the context of clinical assessment, sports performance, ergonomics, or rehabilitation, making it difficult to establish a comprehensive reference dataset. This lack of consolidated normative data presents a challenge for applications requiring standardized anthropometric inputs, particularly the development and optimization of lower-limb robotic and assistive technologies.

The objective of this literature review is to synthesize published lower-limb length measurements from healthy adult populations into a comprehensive normative dataset. By consolidating anthropometric data across the existing literature, this review aims to provide a standardized reference to support biomechanical research and the development of lower-limb assistive technologies, including a lower-limb robotic exoskeleton. The review is limited to studies involving healthy adults with no reported history of musculoskeletal injury or pathology, with the resulting dataset intended to represent normative lower-limb dimensions within this population.

Methods

From February 2 to March 3, 2026, a structured literature review was conducted to identify published lower-limb length measurements in healthy adult populations. Operational definitions were established for four lower-limb anthropometric measurements to ensure consistency across the reviewed literature (Table 1). Specifically, the review focused on femoral length, tibial length, ankle height, and the femur-to-tibia length ratio. Relevant publications were identified through searches of four electronic databases: PubMed, Ovid, SPORTDiscus, and Google Scholar. Studies published between January 1, 1941, and October 28, 2024, were considered for inclusion in the review.

Table 1 Operational Definitions of Lower Limb Length Measurements

Measurement	Length
Femoral Length	Vertical measurement of the femur between proximal and distal anatomical landmarks
Tibial Length	Vertical measurement of the tibia between proximal and distal anatomical landmarks
Ankle Height	Vertical distance from the lateral malleolus to ground height
Femoral: Tibial Length Ratio	Ratio of femoral length to tibial length

All studies reviewed were in the English language. Key search terms included (lower limb OR lower extremity OR leg) AND (length OR distance OR span) AND (tibia OR femur OR lateral malleolus) OR (CT OR computed tomography OR radiograph OR radiography) NOT (children OR adolescents OR youth OR child OR teenage) NOT (replacement OR injury OR trauma OR surgery). Studies that reported values on children or adolescents were excluded. Additionally, studies that reported on individuals with injury or trauma were excluded. No restrictions were placed on assessment protocol, sex, or physical activity levels to capture a comprehensive range of data.

All scientific articles identified from the search criteria underwent a three-stage screening process consisting of a title review, abstract review, and a full-text review. Scientific articles that possessed relevant titles advanced to abstract review, and studies with contextually relevant abstracts were subject to a full-text evaluation. Eligible studies for this literature review met all inclusion criteria and successfully completed all three screening stages. One reviewer evaluated all scientific papers for this literature review.

All eligible papers included had the following information extracted:

1) Bibliographic information (lead author, date published, title, journal)
2) Study design (methods, outcome variables, operational definition of limb length)
3) Population characteristics (age, sex, ethnicity, limb dominance)
4) Results (mean, standard deviation, minimum, maximum)
5)

A weighted average was used to calculate the mean limb length, where each sample size was multiplied by its corresponding mean limb length measurement (Equation 1) or mean standard deviation (Equation 2) and then divided by total sample size, *n*. The minimum and maximum values were directly obtained from each study. The smallest minimum and largest maximum values found were used for the absolute minimum and maximum values for each limb length measurement (Table 1).

$$\boldsymbol{x_w = \frac{\sum_{i=1}^{k} n_i x_i}{\sum_{i=1}^{k} n_i}} \qquad \textit{Equation 1}$$

$$\boldsymbol{s_w = \frac{\sum_{i=1}^{k} n_i s_i}{\sum_{i=1}^{k} n_i}} \qquad \textit{Equation 2}$$

All lower-limb measurements extracted from eligible studies were compiled into a centralized database. For each study, the following information was recorded, where available: study identifier, sample size, measurement type, mean, standard deviation, minimum and maximum values, participant sex (male or female), and limb dominance. The database was organized according to each anthropometric measurement defined in Table 1. For the purposes of this review, a measurement was considered to have sufficient literature if it included more than 1,500 individual data points with representation across both sexes and a broad range of adult ages. To avoid duplication, each data point represented a unique cohort of participants and a single limb length measurement.

Using the information gathered from each study (i.e., mean, standard deviation, minimum, maximum), the 5th and 95th percentiles for the overall dataset were estimated. Because individual participant data was not available from the included studies, the 5th and 95th percentiles could not be calculated directly. Instead, these percentiles were derived from the pooled mean and standard deviation of each measurement under the assumption of an approximately normal distribution, using Equation 3 and Equation 4. The resulting percentiles are intended to provide practical anthropometric design boundaries for lower-limb robotic exoskeleton applications by approximating the range of lower-limb dimensions expected within the target population. However, because these estimates were derived from aggregated summary statistics rather than individual participant data, they should be interpreted as approximate reference values for design and development rather than as precise population percentiles.

$$P_5 = x_w - 1.645 s_w \qquad \textit{Equation 3}$$

$$P_{95} = x_w + 1.645 s_w \qquad \textit{Equation 4}$$

Results

Across all four databases, this literature review initially generated 530 results (Figure 1). All 530 scientific articles underwent initial title screening, with 262 advancing to the abstract review. Of these, 90 articles had contextually relevant abstracts that underwent full-text evaluation. Full-text review resulted in 24 eligible studies that met all inclusion criteria and reported lower-limb length measurement values that aligned with the operational definitions outlined (Table 1.)

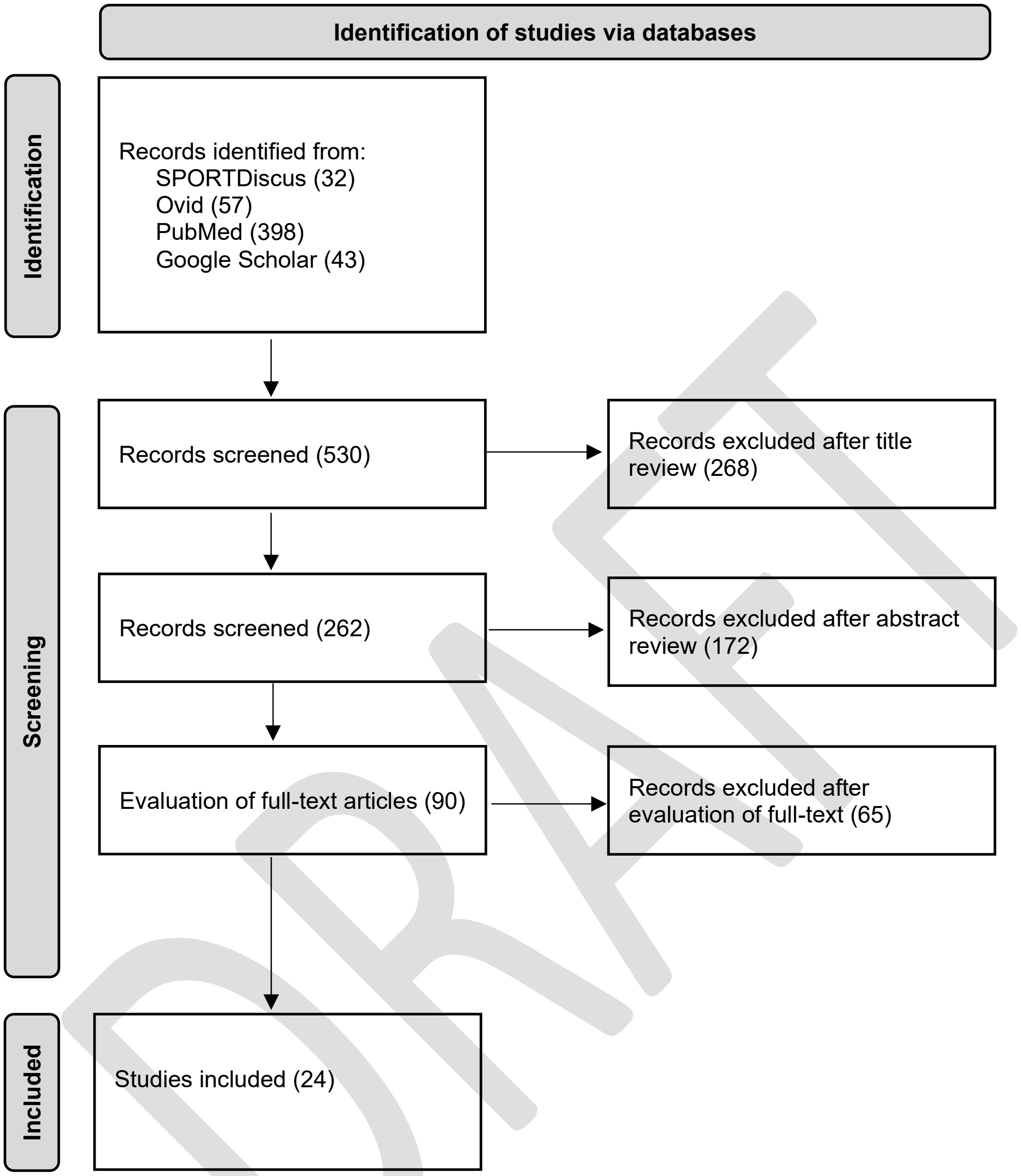

Figure 1 Flowchart of the Literature Review Selection Process

Twenty-four studies reported on the relevant limb length measurements (Table 2). The total pooled sample size across all studies was N = 20197, 68% of these participants were male (N = 13833) and 32% were female (N = 6364). All scientific articles were published between 1941-2024 (Figure 2). Eleven studies reported on both the femoral length and tibial length (Aitken, 2021; Choi et al., 1997; Dayal et al., 2008; Hasegawa et al., 2009; Mahakkanukrauh et al., 2011;

Menéndez Garmendia et al., 2018; Petrovečki et al., 2007; Sarajlić & Cihlarž, 2007; Simon et al., 2023; Strecker et al., 1997; Trotter & Gleser, 1952). Due to incomplete datasets, six of these studies were used to calculate the ratio between the femoral and tibial length (Dayal et al., 2008; Hasegawa et al., 2009; Menéndez Garmendia et al., 2018; Petrovečki et al., 2007; Simon et al., 2023; Trotter & Gleser, 1952). Four studies reported only on the femoral length (Chiba et al., 2018; De Mendonça, 2000; Imai et al., 2020; Pick et al., 1941). Three studies reported only on the tibial length (Banyeh et al., 2022; Duyar & Pelin, 2003; Saco-Ledo et al., 2019). Six studies reported on the distance between the lateral malleolus of the fibula and the ground height (Aguilar et al., 2017; Cao et al., 2023; Jee et al., 2017; Struška et al., 2024; White, 1982; Zeybek et al., 2008)

The twenty-four studies employed a range of measurement tools, broadly divided into direct (contact) instruments and imaging-based methods. Among the contact instruments, six studies used an osteometric board (Chiba et al., 2018; Choi et al., 1997; Dayal et al., 2008; Mahakkanukrauh et al., 2011; Pick et al., 1941; Trotter & Gleser, 1952) four used an anthropometer or stadiometer (Duyar & Pelin, 2003; Imai et al., 2020; Saco-Ledo et al., 2019; Struška et al., 2024), four used a caliper (i.e., anthropometric, digital, or sliding) (Banyeh et al., 2022; Menéndez Garmendia et al., 2018; Pick et al.,1941; Zeybek et al., 2008), and two studies used a metallic bar with metric measurements or tape measurer (Aguilar et al., 2017; Hasegawa et al., 2009). Among the imaging-based methods, four studies used radiograph imaging (Aitken, 2021; Petrovečki et al., 2007; Sarajlić & Cihlarž, 2007; Simon et al., 2023), three used computed tomography scans (Chiba et al., 2018; Imai et al., 2020; Strecker et al., 1997), two used a 3D scanner and/or measurement software tool (Cao et al., 2023; Jee et al., 2017), and one used a dual-energy x-ray absorptiometry scan (Hasegawa et al., 2009). One study did not explicitly define which measurement tool was used, only that the methodology followed standard anthropometric protocols (White, 1982).

Table 2 Summary of included studies

Study	Sample size	Measurement Length	Sex	Reported Age	Measurement Tool
Aguilar, 2017	17	Lateral malleolus height	Male: 6 Female: 11	18-27	Tape measure
Aitken, 2021	753	Femoral length Tibial length	Male: 459 Female: 294	16-83	Radiograph
Banyeh, 2022	191	Tibial length	Male: 89 Female: 102	18-30	Sliding caliper
Cao, 2023	317	Lateral malleolus height	Male: 162 Female: 155	18-30	MEASURE2.1.2 software, INFOOT scanner
Chiba, 2018	224	Femoral length	Male: 116 Female: 108	50.7 ± 17.0	Computed tomography scan, virtual osteometric board
Choi, 1997	57	Femoral length Tibial length	Male: 57 Female: 0	20-86	Osteometric board
Dayal, 2008	169	Femoral length Tibial length	Male: 98 Female: 71	25-70	Osteometric board
De Mendonça, 2000	200	Femoral length	Male: 100 Female: 100	20-59	Metallic bar with metric measurements
Duyar, 2003	231	Tibial length	Male: 231 Female: 0	18-35	Martin anthroprometer
Garmendia, 2018	86	Femoral length Tibial length	Male : 56 Female: 30	19-91	Caliper
Hasegawa, 2009	434	Femoral length Tibial length	Male: 92 Female: 342	18-59	Dual-energy X-ray absorptiometry scan
Imai, 2020	106	Femoral length	Male: 54 Female: 52	48.0 ± 19.8	Computed tomography scan, stadiometer
Jee, 2017	461	Lateral malleolus height	Male: 175 Female:286	20-69	Enfoot 3D Scanner, CCD Camera
Mahakkanukrauh, 2011	200	Femoral length Tibial length	Male: 132 Female: 68	19-93	Osteometric board
Petrovečki, 2007	40	Femoral length Tibial length	Male: 21 Female: 19	31-86	Radiograph
Pick, 1941	150	Femoral length	Male: 142* Female: 8*	24+	Osteometric board, anthropometric caliper
Saco-Ledo, 2019	495	Tibial length	Male: 495 Female: 0	18-55	Harpenden Stadiometer
Sarajlić,2007	273	Femoral length Tibial length	Male: 270 Female: 0 Male: 273 Female: 0	19-58	Radiograph
Simon, 2023	4200	Femoral length Tibial length	Male: 1674 Female: 2526	18-95	Radiograph
Strecker, 1997	355	Femoral length Tibial length	Male: 231 Female: 124	16-78	GE 9800 Quick Computed Tomography Scanner
Struska, 2024	37	Lateral malleolus height	Male: 37 Female: 0	21-51	Anthropometer
Trotter, 1952	100	Femoral length Tibial length	Male : 50 Female 50	24-99	Osteometric board
White, 1982	10852	Lateral malleolus height	Male: 8947 Female: 1905	18-79	No specific measurment tool listed
Zeybek, 2008	249	Lateral malleolus height	Male: 136 Female: 113	18-44	Digital Caliper

Across all twenty-four scientific articles, measurements were obtained from a total of 20197 participants. Several studies reported data from both lower limbs, yielding two measurement values per individual for a given length. However, most studies utilized cadaveric specimens, and the resulting datasets were incomplete, with measurements unavailable for both limbs in all cases. Consequently, while the total number of data points (25672) exceeded the number of participants, it is not a complete doubling of the participant population (Table 3). Because the femoral-to-tibial length ratio drew on the same data as the first two measurement lengths, these data points were excluded from the total.

Table 3 Number of data points for each lower-limb length measurement parameter

Measurement Length	Sex	Data Points
Femoral Length	Male	4351
	Female	3994
Tibial Length	Male	4090
	Female	3792
Ankle Height	Male	9695
	Female	2750
Femoral:Tibial Length Ratio	Male	3341
	Female	3237

Relevant lower-limb measurements (i.e., mean, standard deviation, minimum, maximum) were gathered from each study and aggregated into a database. The complete database was first organized according to each of the four measurement lengths defined in Table 1. This database was further stratified by sex, resulting in six tables for subsequent analysis (i.e., three measurement lengths by two sexes). Each table was used to compute the overall mean, standard deviation, minimum, and maximum values for each measurement length, separated by sex (Table 4). From the consolidated data, graphs were generated in MATLAB for each measurement length to depict the distribution of values across the dataset (Figures 2-5). One study reported a combined-sex femur-to-tibia ratio of 1.28 which was not included in Table 4 (Aitken, 2021).

Because this ratio was calculated using from mean values, a standard deviation could not be calculated (Table 4).

Table 4 Summary of lower-limb length measurement values obtained from literature

Measurement Length	Sex	Mean ± SD	Minimum	Maximum
Femoral Length	Male	45.49 ± 2.47	36.63	53.93
	Female	41.62 ± 3.70	33.98	48.03
Tibial Length	Male	38.03 ± 2.38	31.10	45.48
	Female	34.94 ± 2.06	27.00	43.37
Ankle Height	Male	7.31 ± 0.54	5.00	10.00
	Female	7.01 ± 0.52	4.90	9.50
Femoral: Tibial Length Ratio	Male	1.23	1.19	1.26
	Female	1.23	1.19	1.26

Across the included studies, the operational definitions used for the femoral and tibial length segments varied. Femur length was defined using different proximal and distal landmarks: proximally, studies measured from either the femoral head or greater trochanter; distally, from the medial femoral condyle, lateral femoral condyle, epicondylar region, or bicondylar plane. Tibial length showed similar variation, with proximal reference points including the tibial plateau or intercondylar region, and distal points defined as the medial malleolus or malleolar tip. These differences were addressed by grouping measurements according to comparable anatomical landmarks to facilitate between-study comparison. A summary of these operational definitions across studies is shown in Table 5.

Table 5 Operational definitions for femoral and tibial lengths from included studies

Study	Measurement Length	Proximal Landmark	Distal Landmark
Aitken, 2021	Femoral	Most proximal point of the femoral head	Center of the medial femoral condyle
	Tibial	Center of the medial tibial plateau	Center of tibia's lower articular surface
Banyeh, 2022	Tibial	Most proximal medial condylar point	Most distal point of the medial malleolus
Choi, 1997	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Articular surface of the lateral condyle	Most distal point of the medial malleolus
Dayal, 2008	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Articular surface of the lateral condyle	Most distal point of the medial malleolus
Duyar, 2003	Tibial	Most proximal medial condylar point	Most distal point of the medial malleolus
Garmendia, 2018	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Most proximal medial condylar point	Most distal point of the medial malleolus
Hasegawa, 2009	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Articular surface of the lateral condyle	Most distal point of the medial malleolus
Mahakkanukrauh, 2011	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Intercondylar eminences	Most distal point of the medial malleolus
Petrovečki, 2007	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Articular surface of the lateral condyle	Most distal point of the medial malleolus
Saco-Ledo, 2019	Tibial	Most superior point on the medial border of the tibial head	Most distal point of the medial malleolus
Sarajlić, 2007	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Articular surface of the lateral condyle	Most distal point of the medial malleolus
Simon, 2023	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Midpoint of proximal tibia joint line	Center of tibia's lower articular surface
Strecker, 1997	Femoral	Most proximal point of the femoral head	Lowest point of femoral condyles
	Tibial	Center of the proximal tibial plateau	Center of tibia's lower articular surface
Trotter, 1952	Femoral	Most proximal point of the femoral head	Most distal point of the medial condyle
	Tibial	Articular surface of the lateral condyle	Most distal point of the medial malleolus

Table 6 presents the same pooled anthropometric results reported in Table 4, with the addition of estimated 5th and 95th percentile values. These were computed from the pooled mean and standard deviation to provide approximate lower and upper distribution bounds for each measurement.

Table 6 Summary of lower-limb length measurement values

Measurement	**Sex**	**Mean ± SD**	**Min**	**5th Percentile***	**95th Percentile***	**Max**
Femoral Length	Male	45.49 ± 2.47	36.63	40.10	50.89	53.93
	Female	41.62 ± 3.70	33.98	35.90	47.34	48.03
Tibial Length	Male	38.03 ± 2.38	31.10	32.75	43.14	45.48
	Female	34.94 ± 2.06	27.00	30.70	38.87	43.37
Ankle Height	Male	7.31 ± 0.54	5.00	6.12	8.00	10.00
	Female	7.01 ± 0.52	4.90	5.90	7.77	9.50

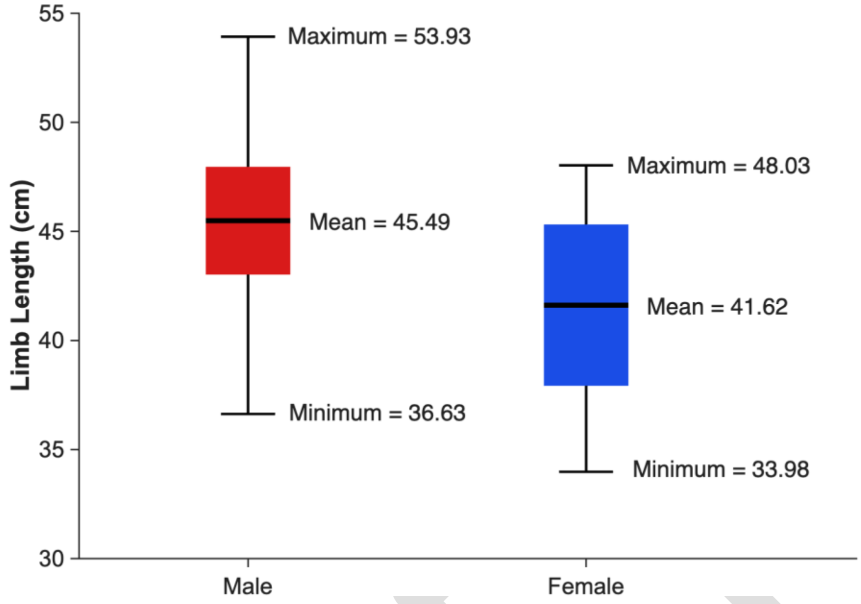

Figure 2 Box-and-whisker plot illustrating femoral vertical length measured between proximal and distal anatomical landmarks for male (red) and female (blue) participants. The y-axis represents limb length (cm). The central horizontal line denotes the mean value, while the lower and upper bounds of each box indicate the estimated 5th and 95th percentiles, respectively. Whiskers extend to the minimum and maximum observed values.

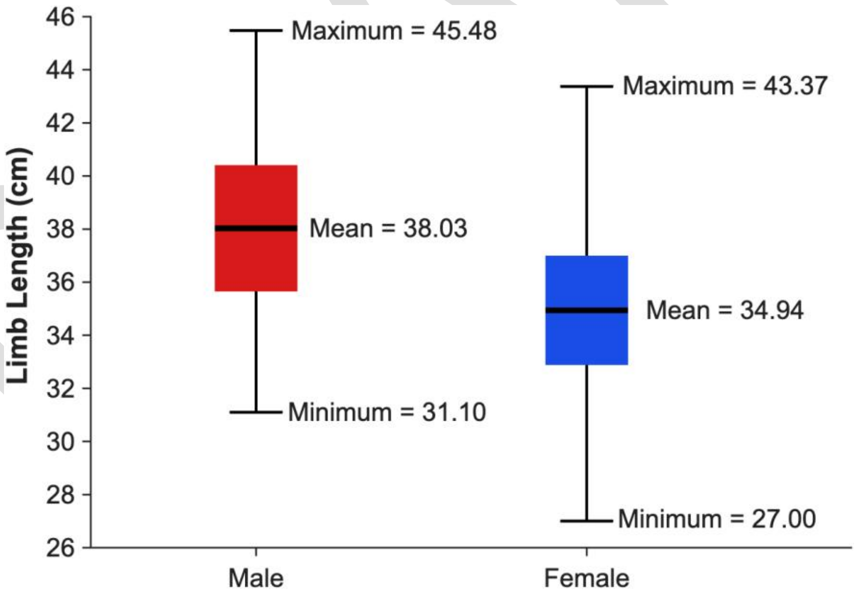

Figure 3 Box-and-whisker plot illustrating tibial vertical length between proximal and distal anatomical landmarks for male (red) and female (blue) participants. The y-axis represents limb length (cm). The central horizontal line denotes the mean, while the lower and upper bounds of each box indicate the estimated 5th and 95th percentiles, respectively. Whiskers extend to the minimum and maximum observed values.

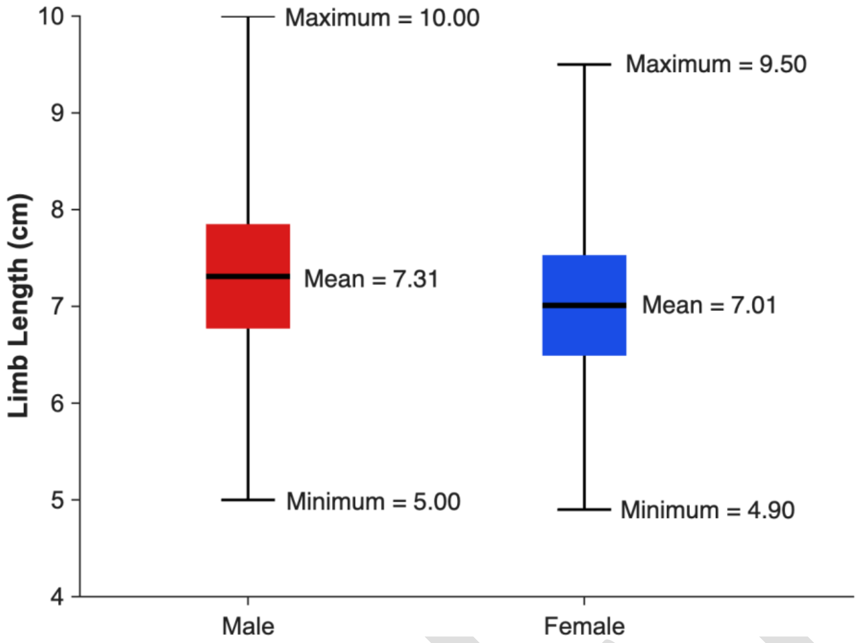

Figure 4 Box-and-whisker plot illustrating the vertical distance from the lateral malleolus of the fibula to the ground for male (red) and female (blue) participants. The y-axis represents ankle height (cm). The central horizontal line indicates the mean, while the lower and upper bounds of each box represent the estimated 5th and 95th percentiles, respectively. Whiskers extend to the minimum and maximum observed values.

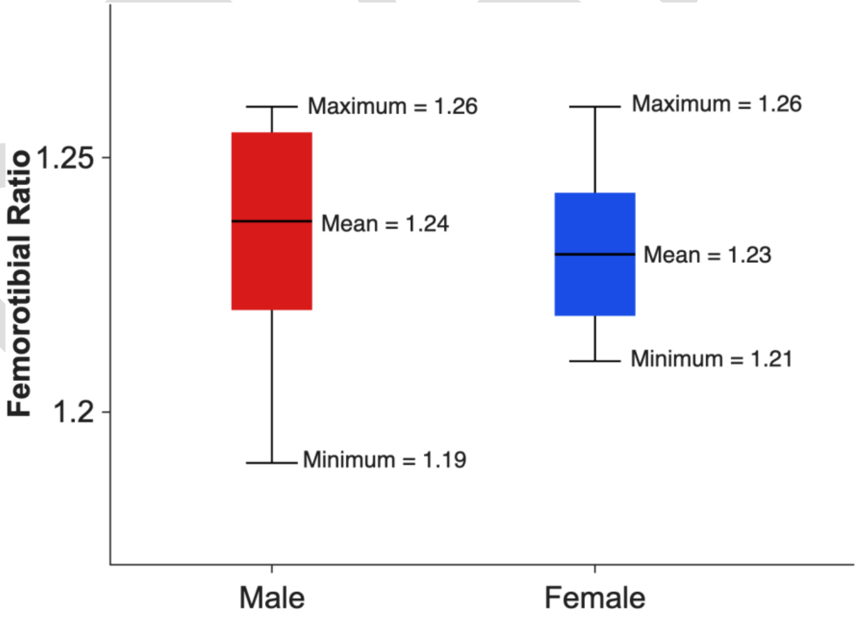

Figure 5 Box-and-whisker plot illustrating the femur-to-tibia length ratio for male (red) and female (blue) participants. The y-axis represents the femur-to-tibia ratio. The central horizontal line denotes the mean, while the lower and upper bounds of each box indicate the estimated 5th and 95th percentiles, respectively. Whiskers extend to the minimum and maximum observed values.

Discussion

The objective of this literature review was to develop a normative database of lower-limb anthropometric measurements for healthy adults to support the design of lower-limb robotic exoskeletons. From 530 records screened, 24 studies met the inclusion criteria, representing 20,197 participants. The resulting database provides normative values for femoral length, tibial length, ankle height, and the femur-to-tibia length ratio using clearly defined anatomical landmarks. Collectively, these measurements establish a quantitative foundation for defining the geometric and functional design requirements of wearable lower-limb assistive devices.

Considerable inter-individual variability was observed in femoral and tibial segment lengths, whereas ankle height and the femur-to-tibia length ratio remained comparatively consistent across the population. Although males demonstrated greater mean femoral and tibial lengths than females, substantial overlap existed between the distributions of both sexes, indicating that individual anthropometric variation is often greater than sex-based differences. In contrast, ankle height exhibited a relatively narrow range with low variability, suggesting that this measurement is less influenced by overall body size than the more proximal limb segments. Similarly, the femur-to-tibia length ratio was remarkably consistent between males and females, indicating that proportional relationships between limb segments are largely preserved despite differences in absolute limb dimensions.

These findings have important implications for the design of robotic exoskeletons. The broad range of femoral and tibial lengths supports the need for adjustable thigh and shank segments to ensure accurate alignment between the mechanical and anatomical joint axes. Misalignment between the exoskeleton and the user can generate undesirable interaction forces, reduce movement quality, and increase discomfort or injury risk (Chen et al., 2024). Conversely, the relatively stable femur-to-tibia ratio suggests that proportional scaling algorithms may provide an effective framework for customizing exoskeleton geometry once a user's overall limb dimensions have been established (Laubscher et al., 2021). Likewise, the limited variability in ankle height indicates that this portion of the exoskeleton may require only modest adjustment, consistent with existing ankle exoskeleton designs that incorporate discrete vertical alignment mechanisms (Lee et al., 2021).

A major source of variability in the compiled anthropometric measurements was the inconsistency in operational definitions across studies. While femoral and tibial lengths were generally measured between comparable proximal and distal anatomical regions, studies differed in the precise landmarks selected, particularly around the knee joint. These methodological differences introduce systematic offsets in reported segment lengths rather than random measurement error. Consequently, although absolute values vary between studies, the underlying anthropometric relationships remain relatively stable. Given the large, pooled sample size and the consistency of overall trends, combining these datasets provides a robust normative reference while highlighting the need for standardized measurement protocols in future anthropometric research.

The primary strength of this review is the development of one of the largest consolidated databases of normative lower-limb anthropometric measurements for healthy adults. By synthesizing data across multiple disciplines, including clinical research, biomechanics, anthropology, and rehabilitation, this review provides a comprehensive reference that can support biomechanical modelling, ergonomic analyses, and the design of lower-limb robotic assistive technologies.

Several limitations should be considered when interpreting these findings. First, variability in anatomical landmark definitions and measurement techniques reduced direct comparability between studies and likely contributed to the observed variability in reported segment lengths. Second, the review was limited to healthy adult populations, and therefore the resulting normative values may not be generalizable to pediatric populations, older adults with atypical anthropometry, or individuals with musculoskeletal injury or pathology. Finally, estimation of the 5th and 95th percentile values was based on published summary statistics rather than individual participant data. These estimates assumed an approximately normal distribution and therefore should be interpreted as practical design reference values rather than exact population percentiles. Nevertheless, comparison with the reported minimum and maximum values demonstrated that all estimated percentiles fell within the observed ranges, providing confidence that they reasonably approximate the expected distribution of lower-limb dimensions in healthy adults.

Conclusion

This white paper synthesized published literature to establish normative lower-limb segment length values across key anatomical measurements used in anthropometric assessment. Data from 24 studies were consolidated to define a solution space for femoral, tibial, and ankle height segment lengths. The resulting dataset provides a consolidated reference for translating lower-limb human geometry into design-relevant parameters for alignment, scaling, and fit in robotic exoskeleton systems. Future work should focus on standardizing anatomical landmark definitions and measurement methodologies to improve between-study comparability. Expanding the dataset to include pediatric populations and clinical cohorts with atypical anthropometry would further enhance the generalizability and utility of the reference framework. Overall, this review integrates previously fragmented anthropometric data into a unified reference resource to support the development and optimization of lower-limb robotic exoskeletons.

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